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16. Abstract (Limit: 200 words) This volume addresses the comparative risks to human health and the environment from land-based and ocean incineration of liquid organic hazardous wastes. Case studies for selected waste streams (polychlorinated biphenyls (PCB's) and ethylene dichloride wastes) were used to compare all aspects of the land and ocean incineration systems, including transportation, handling, storage, and incineration.

Human health risks were found to be very low for both the land and ocean systems. Because of the greater distance from human populations, stack releases from the ocean system result in somewhat lower human health risks than land-based systems.

Use of the ocean system presents a very small probability of an accident involving a hazardous waste spill from the incinerator ship. In the extremely unlikely event of a large spill of PCB wastes in the harbor or bay area, significant environmental damage could occur according to the model used.

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INTRODUCTION AND SUMMARY CHAPTER 1

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) currently is evaluating ocean-based incineration as a method for disposal of hazardous wastes. EPA's Office of Policy Analysis (OPA) asked Industrial Economics, Incorporated (IEc) to work with OPA staff in developing a comparative assessment of the risks posed by land-based and ocean-based incineration systems. This document presents the results of our work.

Ocean- and land-based incineration systems have different physical characteristics and affect different locations and ecosystems. As a result, structuring a consistent comparison is difficult. This report integrates existing information and adds new analyses developed using existing methods and data. No new primary research has been completed. We hope that our method of structuring the analysis and the results developed will assist efforts to evaluate incineration and other technologies for hazardous waste management. However, it is important to understand that the results of this effort are not sufficient to determine the advisability of any specific land- or ocean-based incineration proposal.

The remaining sections of this Chapter summarize:

- the ocean- and land-based incineration systems considered,
- major results and conclusions,

- the major limitations of our work, and
- the organization of this report.

All exhibits referenced in the text are included at the end of the chapter.

INCINERATION SYSTEMS CONSIDERED

Incineration System Components

We separate land- and ocean-based incineration systems into three and four separate physical components, respectively. Both land- and ocean-based systems are defined to include:

- Land Transportation: transport of wastes by truck from the generator site to the incinerator or pier,
- Transfer and Storage: transfer and storage operations at the land-based incinerator, pier, or other storage facilities, and
- Incineration: incineration of the waste.

In addition to these steps, ocean-based incineration systems are defined to include:

- Ocean Transportation: transport of the wastes by ship from the pier facility to the burn zone.

At each of these stages, wastes and hazardous by-products (for example, volatilized fractions or products of incomplete combustion) can be released to the environment. The nature of these releases varies from relatively unlikely releases of large quantities of waste (such as spills from truck or ship accidents) to very likely releases of smaller quantities of waste (such as stack emissions, minor pump leaks, and so forth). We attempt to quantify losses from all of these possible release points.

Our ocean-based system has a configuration similar to that proposed by Chemical Waste Management, Inc. (CWM) to operate the I/V Vulcanus II from Mobile, Alabama to the Gulf of Mexico burn zone. However, we assume that an integrated storage and transfer facility is located at the port. Our land-based system is not based on any single incinerator but combines characteristics of several facilities. Exhibit 1-1 displays the important characteristics assumed for each incineration system.

As Exhibit 1-1 shows, land transportation assumptions for the ocean- and land-based systems are similar. We assume that wastes are transported 250 miles from generator to land-based incinerator or pier. Tank trucks are the assumed mode of land transport in both cases; and weather, road, and other driving conditions are assumed to be "average." While wastes destined for land- or ocean-based systems might travel different distances, changes in the 250 mile trip length do not alter our results significantly.

Transfer and storage characteristics for each case are assumed to be similar and are determined primarily by the configuration of equipment used for handling and storing wastes. Ocean-based incineration requires one extra loading step --- pumping wastes from an onshore storage facility or from the current fixed piping system at Chickasaw into the incinerator ship. The type of storage tanks used also is critical, since the emission characteristics of alternate tanks differ greatly. Our analysis considers both accidental spills during transfer and storage and continuous "fugitive" losses from storage tank vents, pump seals, and so forth. We have not considered releases from major accidents involving fire or explosion at storage facilities. The probability of such events occurring is very low and, because both land- and ocean-based systems require similar storage facilities, the potential for events of this type would be about the same for each system.

Ocean transportation characteristics are unique to the ocean-based system, and have been drawn directly from CWM's proposed plan for operations through Mobile Harbor from Chickasaw, Alabama. These operations will require an 800 kilometer transit through Mobile Harbor, across the continental shelf near the mouth of the Mississippi River, and on to the burn zone.

Finally, Exhibit 1-1 shows the assumed characteristics of the incinerators themselves. Both land-based and ocean-based incinerators are assumed to be liquid injection units with capacities up to 70,000 metric tons per year. This capacity was selected based on the characteristics of the Vulcanus II. Although this capacity is greater than any commercial land-based facility, incinerators of this size are feasible and in operation at some on-site facilities. Consistent with current practice the land-based unit is assumed to employ scrubbers, while the ocean-based unit does not. We assume that these units achieve destruction and removal efficiencies (DRE) of 99.99 to 99.9999 percent depending on the waste burned. In effect, we assume that either system will meet current permit requirements concerning DRE and other operating parameters.

Waste Streams

The environmental transport of wastes and by-products and their ultimate fate and effects depend strongly on the precise composition of the mixture released. In general, adequate data do not exist to predict the transport, fate and effects of mixtures released to the environment. In view of this, we assume two "simplified" waste streams with single hazardous constituents for use in this analysis.

1. A waste containing 35 percent by weight of polychlorinated biphenyls (PCBs). Arochlor 1254 is assumed to be the specific PCB, and the remaining 65 percent of the waste stream is assumed to be non-hazardous. Each system is assumed to burn 56,000 metric tons of this waste stream each year.
2. A waste containing 50 percent by weight of ethylene dichloride (EDC) and 50 percent non-hazardous substances. Each system is assumed to burn 68,400 metric tons of this waste stream each year.

In addition, each waste stream is assumed to include 100 ppm each of arsenic, cadmium, chromium and nickel. These metals are among those specifically regulated by the Agency's draft permit for ocean-based incineration and each has been designated a human carcinogen by EPA's Carcinogen Assessment Group. Although all four have been found in a variety of actual waste streams, it is likely that our assumption overstates the average concentration of carcinogenic metals in liquid incinerable wastes.

Commercial incinerators handle many waste streams of varying composition. Four considerations caused us to assume the simplified wastes described above. First, CWM has requested a permit to burn PCB-containing wastes and thus the possible release, transport and effects of these compounds are of particular interest to EPA. Second, EDC is a common component in many hazardous waste streams currently incinerated and is typical of a large volume of wastes generated by the organic chemicals industry. Third, the physical characteristics and resulting transport behavior of PCBs and EDC in the marine environment are quite different, thus allowing us to illuminate how fundamentally different waste components might behave. Fourth, human cancer potency factors are available for both PCBs and EDC and information is available on the toxic and bioaccumulative effects of the materials in marine organisms.

SUMMARY OF RESULTS AND CONCLUSIONS

This section summarizes the quantities of waste released and the possible human and environmental effects from these releases.

Quantities of Waste Released

Exhibits 1-2 and 1-3 present our estimates of the "expected" annual average release quantities from ocean-based and land-based incineration for the PCB and EDC wastes, respectively. For releases due to accidents, spills and other infrequent events these estimates represent the long-term average release, which includes years with no release and years with one or more releasing events. As a result, actual releases in any single year for these events could range from zero to relatively large quantities if, for example, a truck is involved in an accident that results in a spill. Our calculation of expected quantities released accounts for both the probability of a release and the resulting magnitude of waste lost, and provides one means of comparing average long-term releases from infrequent events with continuous releases.

Each exhibit shows the expected quantity of release for each component of the land- and ocean-based systems. All figures have been rounded to the nearest 100 kilograms (0.1 metric tons). For convenience, a subtotal is provided for releases from transport and handling steps and for incinerator stack releases. Metals included in scrubber effluent are also reported.

Overall, comparison of the expected releases from the ocean-based versus the land-based systems for these two wastes shows that expected release quantities from the transportation and handling components range to roughly 15 percent of the long-term average release expected. The extra transport and handling steps required by ocean-based systems do not add significantly to the long-term expected release, but they do create the remote possibility of a major accident and subsequent release of waste.

Incineration itself accounts for the major release of wastes and hazardous by-products for both wastes and systems considered. The quantities released by incineration are a function of assumptions about metals content and the performance of the incinerator and scrubber. Available estimates of PIC generation are subject to very high levels of uncertainty. Releases from each component are further discussed below.

Land Transportation

Exhibits 1-2 and 1-3 show that the expected release from land transportation will average 2.1 and 2.7 metric tons (MT) per year for the PCB and EDC wastes, respectively. Again, these estimates represent long-term averages. Releases in any year would vary from zero to larger quantities if a spill occurred. The slightly greater release estimated for the EDC waste reflects the larger quantity of this waste assumed to be handled by each system. Because land transportation has the same configuration in each system, there is no difference in the release quantities expected for the land- versus ocean-based system.

Our analysis of releases from land transportation considers two types of potential losses -- spills from vehicular accidents and spills from enroute container failures. We base our estimates of the frequency of such events and of the size of the resulting spills on data provided by the U.S. Department of Transportation (DOT). These data pertain to all tank trucks carrying hazardous materials. Use of the DOT data with our assumptions regarding miles travelled results in an expected .18 and .26 releasing vehicle accidents per year for the PCB and EDC wastes, respectively. The annual number of container failures is estimated at .23 and .32 for the PCB and EDC wastes. The average fraction of cargo released in vehicular accidents is about 40 percent. In contrast, spills from container failures typically release only about 4 percent of the cargo in the container.

Information supplied by hazardous waste services firms indicates that the DOT accident rates are higher than those experienced by these firms. This probably is due to management practices undertaken by such firms to reduce the probability of accidents and to their use of stainless steel tanks that are more resistant to rupture than are aluminum tanks. Thus, we believe that our estimates of releases from land transportation are conservative. These estimates represent, on average, about 0.5 percent of the number of annual transportation-related releases of hazardous substances in EPA Region IV.

Transfer and Storage

Our analysis of wastes released from transfer and storage considers three types of releases: spills when unloading wastes from tank trucks; spills from equipment at waste transfer and storage facilities; and fugitive emissions from transfer and storage. As shown in Exhibits 1-2 and 1-3, the expected quantity released from transfer and storage activities is slightly over one metric ton per year for both systems and waste streams considered. These release estimates are based on information developed by Arthur D. Little, Inc. and DOT.

Spills from the transfer and storage component are fairly infrequent events. They are estimated to occur at a rate of about 0.04 to 0.05 per year for the transfer of wastes from tank trucks and at a rate of about 0.03 to 0.04 per year for equipment and storage tanks. The ocean incineration system has one additional component -- the loading hose to transfer wastes to the ship. We estimate the rate of spills from the hose at about 0.002 to 0.003 per year, with the average spill size about 6 to 7 MT. It is likely that spills of this type would be contained either on the deck of the Vulcanus or by booms placed around the vessel during loading. Spills from truck unloading or from equipment or storage tanks are also likely to be contained in the facility. Fugitive emissions would account for about 0.6 to 0.7 MT per year of this amount. The number of spills expected from this component of land- or ocean-based incinerators would represent, on average, less than 0.1 percent of the number of spills of hazardous material likely from fixed facilities in EPA Region IV.

Ocean Transportation

The ocean transportation component of ocean-based incineration is the only major component of the system that has no parallel in a land-based operation. Therefore, potential releases from ocean transportation are of special interest when comparing the relative risks of land- and ocean-based incineration systems.

Incineration ships have operated off the coast of Europe in the North Sea since 1972. About 320 voyages have been made and about 650,000 metric tons of hazardous waste have been incinerated. No casualties such as collisions, groundings, rammings, or fires have occurred, nor have there been any spills from loading these ships in port. Although a very good safety record has been established, the number of voyages completed is too small to be used directly in estimating statistically the probability of spills.

In view of this, EPA asked Engineering Computer Optecnomics, Inc. (ECO) to develop estimates of spill rates based on the worldwide historical record of tank ships of a similar size class. Spill rates were developed for three impact type accidents (collisions, groundings, and rammings) and for non-impact type accidents (fires, explosions, structural failures, and capsizings). Spill rates were developed for four locations of interest -- pier and harbor, Mobile Bay, coastal area, and burn zone. Estimates were also developed of the percentage of spills likely to involve one, two, or three or more tanks -- 80 percent, 15 percent, and 5 percent, respectively.

The historical spill rates were adjusted to take into consideration the design of the Vulcanus (double hull, double bottom construction and the use of a controllable pitch propeller and bow thruster), operating restrictions to be imposed by the Coast Guard (escorts by tug boats and a Coast Guard vessel, imposition of a 300 foot moving safety zone, and limitation of transits to daylight hours and in conditions of above average visibility), and the soft bottom conditions in the Gulf. The precise effect that these factors may have in reducing spill rates is difficult to determine. ECO's adjustments were based on published studies, observed differences in spill rates, kinetic energy levels likely for accidents in different locations, and professional judgment.

The expected annual releases of 0.6 MT for PCBs and of 0.8 MT for EDC shown in Exhibits 1-2 and 1-3 are relatively small and represent average releases expected over a very long time. Spills from the vessel would be very infrequent events. We estimate that the frequency of all spills for the Vulcanus is about one per 1,200 operating years. However, the frequency of spills estimated for any particular location is less. For example, the overall spill rates for the pier and harbor area, Mobile Bay, Coastal area, and the burn zone are about one per 3,000, 10,000, 4,000 and 6,000 operating years, respectively. These estimated spill rates are for all sizes of spills. Spills involving two or three or more tanks would be extremely unlikely events. For example, the estimated rates for spills involving two and three or more tanks in Mobile Bay are about one per 67,000 and 200,000 operating years, respectively.

The preceding estimates of releases are conservative, in that we assume that any tank involved in a spill releases its entire contents and that the entire ship's cargo is released in accidents involving three or more tanks. In addition, the estimates do not reflect the effects that remedial actions may have in removing wastes from the marine environment. As a condition of their permit, hazardous waste operators are required to develop a contingency plan for handling spills. Efforts to contain and recover spills are most likely to be successful in enclosed areas or in shallow waters, such as the pier and harbor area and Mobile Bay. However, estimating the effectiveness of remedial actions was beyond the scope of this study.

The tonnage carried by the Vulcanus is small in comparison to commercial shipments of petroleum and hazardous substances in the Gulf area. For example, the cargo carried by the Vulcanus would be only about 0.01 percent of petroleum and hazardous substances transported annually in the Gulf area. Since the Vulcanus has a lower spill rate than other vessels, the expected volume of releases from the Vulcanus, in a statistical sense, is only about 0.002 percent of expected releases from ongoing shipments of petroleum and hazardous substances in the Gulf area.

Incineration

Incineration itself is the major release point in both systems. Metals account for the largest releases when burning the PCB waste, with undestroyed wastes providing a minor contribution.[1] Our estimates of undestroyed wastes for both systems assume 99.9999 percent destruction of the PCB waste stream. Our estimates of metals emissions result from our assumptions about metals concentrations in the waste. Metals are transferred to scrubber effluent in the land-based case by use of a scrubber which is assumed to remove from 50 to 90 percent of the four metals considered. Thus, stack emissions of organics and metals in the land case are about 20 percent of those predicted for the ocean-based case.

Exhibits 1-2 and 1-3 present the expected annual average release quantities for the incineration component of both systems. Total organics and metals released from incineration of the PCB wastes is 22.5 metric tons per year for both systems if one includes both stack releases and scrubber effluent. Total organics and metals released by the ocean-based incinerator for the EDC waste is more than 50 percent greater than that expected for the land-based case (54.8 MT compared to 34.8 MT). This difference is due primarily to the higher level of PIC release estimated for the ocean case.

Products of incomplete combustion (PICs) are not expected in significant quantities for the PCB waste based on EPA's trial burn data. However, the results of these trial burns are subject to large uncertainty and considerable debate because of the procedures used and the limited number of PIC compounds that were considered. Thus, our estimates of PIC emissions for the PCB waste (.000000006 metric ton per year and .00002 metric ton per year for the ocean and land cases, respectively) could be in error by many orders of magnitude. In addition, we do not know of any complete explanation for the lower level of PIC generation found for ocean-based PCB incineration and the higher level found for ocean incineration of general organic waste relative to incineration on land. Alternate estimates of PIC generation and the resulting human health effects are analyzed in later chapters and appendices of this report.

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[1] Note that if incinerated waste streams contain significantly less carcinogenic metals than we have assumed, the total quantity of stack emissions released from each system would drop dramatically. Further, releases from the transportation and transfer/storage components would become the major contributors to total release.

In addition to the compounds reported in these exhibits, we also analyzed the release of chlorine at incinerators in both systems and the disposition of the chlorine to the atmosphere and, for the land-based system, to scrubber effluent and sludge. Our results show that 10,505 and 25,034 metric tons of hydrochloric acid (HCl) will be released from the incineration of the PCB and EDC wastes, respectively. In the ocean case all HCl is released to the atmosphere. In the land-based case the scrubber captures 99 percent of the HCl and neutralizes it. Thus, most chlorine in the land case is disposed as scrubber sludge or effluent.

Effects From Incinerator Releases

We estimated and compared possible human health effects due to releases from the incinerator and due to fugitive releases from transfer/storage equipment located at the land-based incinerator or the pier. We also considered possible environmental effects of these releases.

Human Health Effects

Our analysis of human health risks estimates the incremental risk of developing cancer for a hypothetical "most exposed individual" (MEI) who resides at the location of the highest overall risk due to air concentrations resulting from incinerator stack and transfer/storage fugitive releases. For the land-based system, the location of the MEI is based on Census data; whereas for the ocean-based system the MEI is assumed to reside at that point on the coast where modelled concentrations are highest averaged over a year. These risk estimates assume 70 years of continuous exposure. In the ocean case different areas are affected by stack emissions (the coastline downwind from the burn zone) and transfer/storage fugitive releases (the area around the port), while for the land-based case the same area is affected. Our calculations of risk for the land-based system consider two alternative sites for the incinerator, in Texas and Arkansas.

We chose to estimate risks to the most exposed individual in order to estimate the largest risks likely to be suffered by any person due to the releases considered. While we could have considered the average incremental risk across the entire human population affected by each system, this metric requires estimation of the total exposed population and all levels of exposure -- a difficult and controversial task given the long distances and persistence of some compounds considered here. In general, other risk analyses have found that average population risks range from one to four orders of magnitude lower than the risk to the MEI.

Exhibit 1-4 presents the incremental risk of developing cancer for the most exposed individual due to releases from land- and ocean-based fugitive (transfer/storage) and stack releases. As shown, the incremental risks from land-based incineration releases are about three chances in one-hundred thousand for the locations and wastes considered. Virtually all of the incremental risk to the MEI is due to stack releases, with fugitive releases resulting in increased risks of less than one in a million. Incremental risks to the most exposed individual at the coastline for the ocean-based system range from one in one million to 6 in ten million. As shown, the risks from fugitives to the MEI near the port facility are less than two per hundred million.

The data and methods used to generate these incremental risk estimates are highly uncertain and tend to overestimate expected human health effects. Thus, the absolute risk levels indicated by these figures must be interpreted with caution. EPA has completed studies of incremental risks from other hazardous pollutant releases using similar methods with similar uncertainties and biases. For example, a recent study on toxic air pollutants found that, on average, individuals in the U.S. face incremental cancer risks of about 4 to 6 chances in ten thousand.2/ Using this estimate as the base for comparison, incremental risks to the persons most exposed by the incineration systems considered here would be one to three orders of magnitude lower.

Exhibit 1-5 presents more detailed information concerning the sources of the incremental cancer risks for the incineration systems considered. This exhibit reports the contribution of principal organic hazardous constituents (POHCs), PIC and metals emissions to the total incremental risks suffered by the MEI. For

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2/EPA, The Magnitude and Nature of the Air Toxics Problem in the United States, Draft Report, Office of Air and Radiation and Office of Policy, Planning and Evaluation, 1984.

convenience, risks due to fugitive emissions from transfer and storage operations are not included in the figures in Exhibit 1-5.

The estimates in Exhibit 1-5 show the relative magnitudes of incremental risk caused by each stack component for both wastes and systems considered. As shown, POHC and PIC releases cause risks that are from one to five orders of magnitude less than risks from metals. Thus, metals account for from 90 percent to virtually all of the incremental risks calculated for stack emissions. However, as noted earlier, it is likely that our assumptions overstate the average concentrations of carcinogenic metals in liquid incinerable wastes. Risks from POHC releases are less than 1 per billion for the ocean system and less than 2 per 10 million for the land system. Risks from PIC releases are less than 4 in one billion for the ocean system and less than 2 in 1 million for the land-based system. Thus, risks from both PICs and POHCs in each system are low.

Exhibit 1-6 presents the ratio of the incremental risks from land-based versus the ocean-based stack releases. The figures in this exhibit were calculated by dividing the land-based risk estimates in Exhibit 1-5 by those shown for the ocean-based system. Thus, the figures in Exhibit 1-6 indicate the relative size of risks estimated for the land-based versus the ocean-based system considered. For example, Exhibit 1-6 indicates that, for the PCB waste, land-based emissions create about 40 times more incremental risk to the MEI than do ocean-based emissions. For the EDC waste, the ratio of land to ocean risk is about 30.

Exhibits 1-5 and 1-6 show that, given our assumptions, there is roughly 30 to 40 times more incremental risk from metal released from land systems. Changes in the type and concentration of metals in the waste could reduce these risk estimates by several orders of magnitude but would not change the relative performance of the land and ocean systems. Different assumptions about the performance of the land-based scrubber in removing metals, or about the atmospheric transport of metals over the ocean could affect the relative performance of the two systems considered. While different assumptions could broaden or narrow the differences in metals risk, it is unlikely that ocean-based systems would generate more incremental risk than land-based systems.

These exhibits also show that the land-based system generates about 300 times more incremental risk from POHC emissions. The transport behavior of PICs is similar to that of POHCs and thus, for similar quantities and toxicities of release, PIC risks should show the same ratios. However, our analysis of trial burn data indicates that land- and ocean-based systems can generate very different quantities of PICs.

EPA's trial burn data indicate wide variation in PICs generated by different incinerators from different waste streams. The results of these burns are subject to great uncertainty and considerable debate. For the PCB waste, our analysis uses a PIC generation rate for the ocean-based system that is 10,000 times lower than that used for land since this rate is derived from trial burn data. When combined with the additional advantage of the ocean-based system in being further from human populations, the land-based unit generates over 1 million times the risk of the ocean system for PICs. Thus, our relative estimates of PIC generation from the PCB waste would have to be in error by a factor of one million for the land and ocean systems to present equivalent risks from PICs. Again, note that the absolute risks estimated for PICs from both systems are very low.

Our assumption regarding the amount of PICs from EDC wastes is quite different. For this waste, trial burn data suggest that the ocean-based unit will generate about 30 times more PICs than the land system. Despite the ocean system's exposure advantage, this lowers its ratio of risk compared to the land system to a factor of 8. While changes in relative PIC generation that are greater than an order of magnitude could make PIC risks from land and ocean systems equivalent or show land systems to be safer, we believe that such changes are unlikely.

Although the absolute numbers reported in Exhibits 1-4 and 1-5 are uncertain and biased to overestimate incremental risks, the relative differences shown in Exhibit 1-6 are more certain and would be altered only by changes in the relative performance of the ocean- and land-based systems. Overall these results generally indicate that the human health risks posed by either system are relatively low, with the risk from the ocean-based system about one to two orders of magnitude less than from the land-based system. This general result was expected, since the burn zone is about 200 kilometers distant from the coast, allowing residual emissions to disperse and to partly settle out before reaching land, and since the plume emitted during trial burns has never been detected at the shoreline.

Along with incremental risks due to inhalation of hazardous compounds, we also considered incremental risks due to ingestion of foods contaminated by wastes or hazardous by-products from ocean- and land-based stack emissions. Although data and methods in this area are extremely limited, we found insignificant incremental risks from this ingestion route of exposure.

Environmental Effects

In addition to the human health effects summarized above, we considered the possible environmental effects that might result from incinerator stack releases. For the ocean-based case, we asked Applied Science Associates, Inc. (ASA) to estimate the deposition of stack releases to the ocean surface, the transport of these materials in the water column and sediments and resulting effects on the marine ecosystem. ASA's analyses indicate that no measurable effect on the marine ecosystem is expected due to stack releases from the EDC waste. The analysis of the PCB waste is complicated by the persistence of the compound and by scientific uncertainty about the role of the ocean's surface (the "microlayer") in capturing and concentrating atmospheric pollutants and providing these materials to the marine ecosystem. Notwithstanding these uncertainties, ASA's analyses indicate that long-term continuous burning of the PCB waste at the levels assumed here would not result in a measurable effect on the marine ecosystem. Information developed on the background atmospheric flux of PCBs into the Gulf waters indicates that it would be about two to three orders of magnitude greater than that from incineration of PCBs.

We were unable to complete a similar analysis of the effects on terrestrial ecosystems caused by land-based stack releases. However we did consider the possible environmental effects from the release of scrubber effluent and sludges from the land-based system. Because discharge of scrubber effluent and sludge is regulated by the Clean Water Act and the Resource Conservation and Recovery Act, respectively, disposal of these materials would have to be carried out in a manner approved by environmental permitting authorities. Thus, we assume environmental damage from these discharges is minor.

Effects From Ocean Transportation Releases

In addition to the effects from incinerator stack and fugitive releases, we also characterized possible human and environmental effects resulting from spills in the marine environment. Although the probability of a spill is very low, the magnitude of the resulting effects is of interest in public deliberations about ocean- versus land-based incineration systems. We considered the likely effects of release of cargo from the vessel at sites within Mobile Harbor, over the continental shelf on the path to the burn zone, and in the burn zone itself.

Human Health Effects

Exhibit 1-7 presents information about the potential for human health consequences from loss of the entire vessel cargo. Volatilization of such a spill could expose human populations to high concentrations of hazardous constituents for short periods of time. Because of the acute nature of these exposures, we compared the estimated dosage received by human populations in the first 24 hours after a spill to the Threshold Limit Value (TLV) for PCBs and EDC. The TLV represents the dosage to which a worker can be exposed with no adverse health effects such as coughing, dizziness, and longer-term health damage. We adjusted the TLVs to account for continuous exposure rather than exposure for only eight hours per day. In all calculations we assume that the human population is directly downwind from the spill site and that the entire cargo of the vessel is released.

As shown in Exhibit 1-7, we estimated the ratio of 24 hour dosages to adjusted TLV's for spills in Mobile Harbor at one and 15 kilometers from the city of Mobile, for spills over the continental shelf near the mouth of the Mississippi River, and for spills in the burn zone. The results show that spills of the entire cargo of either waste one kilometer from the city of Mobile could cause human health problems. Spills at the other locations are not expected to cause acute human health problems.

Environmental Effects

Exhibit 1-8 presents a summary of the potential effects to the marine ecosystem from spills of half a tank in the three locations described previously. The ecosystem effects are summarized by changes in biomass levels and in bioconcentration levels for PCBs and EDC. For PCBs we consider both floating and sinking cases, since this compound, although heavier than water, might float if entrained in lighter-than-water materials. For EDC, we consider only a sinking case, which results in rapid diffusion since this compound is soluble in water. We also modelled the effects of larger spills of 2 tanks and 8 tanks. As noted earlier, for modelling purposes we assumed no actions were undertaken to contain and remove the spill.

Exhibit 1-8 indicates that EDC spills would have relatively minor effects on the marine ecosystem. These small impacts are the result of this compound's rapid diffusion to low concentration levels and its relatively low toxicity to marine species. In addition, bioconcentration of EDC is not a significant phenomenon. The same results hold for larger size spills.

In contrast, spills of PCBs are modelled to have major effects on the marine ecosystem. These effects range from being quite severe in the Bay (substantial reduction in benthic species and large bioconcentration effects on fish and shrimp) to less severe in the burn zone area. Since PCBs are a persistent compound such effects are expected to last a long time. Bioconcentration effects in commercial and recreational species would be of most concern in the Bay and contaminated shelf areas. In the event of larger or smaller size spills, the magnitude of bioconcentration effects is approximately linear with regard to quantity released.

Estimating the effects of spills of persistent compounds such as PCBs in the marine environment is an imprecise science at best. Because of substantial uncertainties regarding the long term fate of PCBs in the marine environment and the biological mechanisms involved in the food web, the results of the modelling effort should be viewed as a general indication of potential effects rather than as a precise measure of those effects.

LIMITATIONS

All of our analyses are subject to many limitations and caveats due to uncertainties in the data and methods that we use. These limitations and caveats are explained fully in the chapters and appendices of this report. All of our results should be interpreted with caution, and with a complete understanding of all of these limitations. Some of the general limitations of the analyses are described below.

1. By design this analysis is limited to considering only incineration systems. It does not consider potential environmental or economic risks or benefits from use of other methods of hazardous waste treatment, storage or disposal.

2. The analyses reported here are applicable only to the specific land- and ocean-based cases examined. Results for other locations, wastes and technologies could vary substantially from the information reported here.

3. We have attempted to structure incineration systems and wastes typical of actual or likely practice so as to generate an expected rather than a best or worst case analysis. However, data limitations have required use of many conservative assumptions in our estimates of release quantities, and the methods for estimating effects of releases generally err on the side of overestimation. Thus, our overall results overestimate releases and resulting effects from the incineration systems considered.

4. We have not considered a number of effects which might result from releases from the ocean- and land-based systems. In particular, we have not analyzed the possible effects of releases on terrestrial ecosystems.

5. Our analysis of the quantity of and effects from stack releases for both systems is based on assumptions about incinerator and scrubber performance and waste composition, and on results from EPA-sponsored trial burns. The data on PIC generation developed from the trial burns is extremely uncertain and subject to debate.

6. The estimates of the effects of spills into the marine environment assume that no mitigating activities are completed.

In view of the above, the absolute release and effects estimates for land- and ocean-based systems are less meaningful than the relative differences shown between the two systems. Our results are particularly sensitive to factors (such as PIC emissions, scrubber efficiency, and so forth) that alter the relative performance of the two systems considered.

ORGANIZATION OF THIS REPORT

All of the methods, data and results for our comparison of the risks of land- and ocean-based incineration are detailed in the remaining chapters and appendices of this report. These materials are organized as follows.

Chapter 2	provides an overview of the methods used in the comparison of ocean-based versus land-based incineration systems.
Chapter 3	presents estimates of the waste quantities released from the land transportation component of each system.
Chapter 4	presents estimates of the waste quantities released from the transfer and storage component of each system.
Chapter 5	presents estimates of the waste quantities released from the ocean transportation component.
Chapter 6	presents estimates of the wastes and hazardous by-products released from incineration itself in both systems.
Chapter 7	describes the human health and environmental effects of releases from ocean transportation.
Chapter 8	describes the human health and environmental effects of releases from land- and ocean-based incinerators.
Appendix A	describes the voyage plan for the Vulcanus II and the resulting waste throughput.

Appendix B	presents detailed estimates of releases from the transfer and storage component.
Appendix C	presents detailed estimates of releases from ocean transportation.
Appendix D	describes the human health effects due to releases from land-based incinerators.
Appendix E	presents estimates of the generation and composition of products of incomplete combustion (PICs).
Appendix F	describes the generation, composition and disposition of scrubber effluent at land-based incinerators.
Appendix G	describes the human health effects due to releases from ocean-based incinerators.
Appendix H	describes the human health effects due to ocean transportation releases.
Appendix I	describes the marine ecosystem effects resulting from ocean transportation releases.

All exhibits follow the chapter or appendix where they are first referenced.

Exhibit 1-1

SUMMARY OF INCINERATION SYSTEM COMPONENTS

Component	Ocean-based System	Land-based System
Land Transportation	Tank trucks (5000 gallons) 250 miles "Average" weather, roads, etc.	Tank trucks (5000 gallons) 250 miles "Average" weather,roads, etc.
Transfer and Stroage	Storage at pier in two floating-roof tanks. One truck unload One load to vessel	Storage at incinerator in two floating-roof tanks. One truck unload
Ocean Transportation	800 km (500 miles) to burn zone Specific path from Mobile to zone Vessel specifications and operations plan as per CWM for Vulcanus II	None

Exhibit 1-1
(continued)

SUMMARY OF INCINERATION SYSTEM COMPONENTS

Component	Ocean-based System	Land-based System
Incineration	Liquid Injection, no scrubber DRE=99.99 or 99.9999 Throughput to 70,000 MT/year	Liquid Injection,with scrubber DRE=99.99 or 99.9999 Throughput to 70,000 MT/year

Exhibit 1-2

SUMMARY OF EXPECTED QUANTITIES RELEASED PER YEAR *
PCB Waste
(metric tons per year)

Release Point	Ocean-based System	Land-based System
Land Transportation	2.1	2.1
Transfer and Storage	1.2	1.1
Ocean Transportation	0.6	--
Subtotal	3.9	3.2
Incineration		
Undestroyed Wastes	0.1	0.1
PICs	0.0	0.0
Metals	22.4	4.5
Subtotal (Stack)	22.5	4.6
Scrubber Effluent Metals	--	17.9
Total Organics and Metals	26.4	25.7

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* For releases due to accidents, spills and other uncertain events these estimates represent the long-term average release which includes years with no release and years with one or more releasing events.

Source: IEc Analysis

Exhibit 1-3

SUMMARY OF EXPECTED QUANTITIES RELEASED PER YEAR *
EDC Waste
(metric tons per year)

Release Point	Ocean-based System	Land-based System
Land Transportation	2.7	2.7
Transfer and Storage	1.2	1.1
Ocean Transportation	0.8	--
Subtotal	4.7	3.8
Incineration		
Undestroyed Wastes	6.8	6.8
PICs	20.6	0.6
Metals	27.4	5.5
Subtotal (Stack)	54.8	12.9
Scrubber Effluent Metals	--	21.9
Total Organics and Metals	59.5	38.6

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* For releases due to accidents, spills and other uncertain events these estimates represent the long-term average release which includes years with no release and years with one or more releasing events.

Source: IEc Analysis

Exhibit 1-4

SUMMARY OF INCREMENTAL CANCER RISK TO MOST EXPOSED INDIVIDUAL FROM INCINERATOR RELEASES

	PCB Waste	EDC Waste
Ocean-based System		
Stack (coastline)	6.37E-7	1.06E-6
Fugitives (port)	2.02E-8	4.97E-10
Land-based System (average of two sites)		
Stack	2.74E-5	3.14E-5
Fugitives	7.05E-7	1.69E-8
Total	2.81E-5	3.14E-5

Source: Exhibits 8-4, 8-5

Exhibit 1-5

INCREMENTAL CANCER RISK TO MOST EXPOSED INDIVIDUAL BY TYPE OF STACK RELEASE

	PCB Waste	EDC Waste
Ocean-based System		
POHCs	1.45E-10	5.51E-10
PICs	1.68E-12	3.36E-9
Metals	6.37E-7	1.06E-6
Total Stack	6.37E-7	1.06E-6
Land-based System (average of two sites)		
POHCs	5.13E-8	1.43E-7
PICs	1.79E-6	2.59E-8
Metals	2.56E-5	3.12E-5
Total Stack	2.74E-5	3.14E-5

Source: Exhibits 8-3, 8-4

Exhibit 1-6

RATIO OF INCREMENTAL CANCER RISK FOR LAND- VERSUS OCEAN-BASED INCINERATORS BY TYPE OF STACK RELEASE

	PCB Waste	EDC Waste
POHCs	354	260
PICs	1,070,000	8
Metals	40	29
Total	43	29

Source: Exhibit 1-5, IEc Analysis

Exhibit 1-7

SUMMARY OF HUMAN HEALTH EFFECTS FROM LOSS OF ENTIRE VESSEL *

(ratio of 24 hour dosage to adjusted TLV)

Release Location	PCB Waste	EDC Waste
Mobile Harbor		
1 Kilometer	1.3	1.9
15 Kilometers	0.06	0.12
Continental Shelf	0.019	0.002
Burn Zone	0.0019	0.0004

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* The probability of a spill involving three or more tanks of the vessel in any location is about one in 24,000 per year, and in the pier, harbor, and bay area is about one in 50,000 per year.

Source: Exhibit 7-18

Exhibit 1-8

SUMMARY OF MARINE ECOSYSTEM EFFECTS FROM SPILLS OF HALF A TANK

	PCB Waste		EDC Waste	
Release Location	Effect on Biomass	Bioconcentration Levels	Effect on Biomass	Bioconcentration Levels
Mobile Bay				
Floating Case	Small overall, severe reduction for benthos	3 to 5 orders of magnitude	Not Considered	Not Considered
Sinking Case	Uncertain	Uncertain	Minor	Minor
Continental Shelf				
Floating Case	Uncertain	Uncertain	Not Considered	Not Considered
Sinking Case	Small overall, substantial for benthos	2-3 orders of magnitude	Minor	Minor
Burn Zone				
Floating Case	Uncertain	Uncertain	Not Considered	Not Considered
Sinking Case	Minor overall, substantial for benthos	1-2 orders of magnitude for benthos and demersal fish	Minor	Minor

Source: IEc Analysis

INTRODUCTION

This chapter introduces the analytic methods used to estimate releases of waste and hazardous by-products from ocean- and land-based systems and to characterize the effects of these releases. In addition, the chapter presents the sources of data and the important assumptions used in this study. The sections below review our rationale for structuring the ocean- and land-based systems as we have, the methods and data used to estimate releases from each component of these systems, and the metrics and methods selected to characterize the effects of these releases. The final section provides some thoughts on the types and magnitudes of uncertainty in our results.

INCINERATION SYSTEM STRUCTURE

As indicated in Chapter 1, the analysis of the ocean-based incineration system is based on Chemical Waste Management, Inc.'s (CWM) proposal to operate the Vulcanus II from Chickasaw, Alabama through Mobile Bay to the Gulf of Mexico burn zone. CWM's proposal envisions delivery of wastes to Chickasaw in tank trucks; transfer, storage and loading of wastes at an integrated port facility; and transport to the Gulf burn zone and incineration aboard the Vulcanus II. Because CWM has not yet developed waste storage capacity at Chickasaw, we also analyze an operation in which wastes are delivered from generators to intermediate storage at CWM's existing Emelle, Alabama storage facility--150 miles inland from Chickasaw--and are trucked from there to the port to be loaded directly onto the Vulcanus. This operation increases the total distance that the wastes are shipped and the number of transfer operations involved in delivering the wastes to port.1/

The analysis of land-based incineration is based on a hypothetical incineration system, the characteristics of which reflect (1) data on several existing incinerators and (2) our assumptions about similarities and differences between a typical land-based system and CWM's proposed operation. We employ a hypothetical land-based system for two reasons. First, because numerous land-based incinerators may offer an alternative to incineration aboard the Vulcanus, we did not wish to tie our analysis to the configuration or location of a single facility. Second, the throughput of PCB wastes for the Vulcanus exceeds the capacity of each of the three land-based incinerators currently permitted to burn PCBs. Since comparison of the risks from land- and ocean-based systems requires identical waste throughputs, the use of a hypothetical land-based unit is necessary.

Our comparison of risks from land- and ocean-based facilities is based on annual throughput of 56,000 metric tons of the PCB waste or 68,400 metric tons of the EDC waste defined in Chapter 1. These throughputs are achievable if CWM does not develop waste storage capacity at Chickasaw. If waste storage capacity is installed at the port, our calculations show that maximum throughput for the ocean-based system could increase by 35 to 55 percent (see Appendix A). We have used the lesser throughputs as the basis for our analysis for two reasons:

1/We have not examined potential releases resulting from systems like those proposed by Seaburn, Inc. and Oceanic Environmental Services, Inc. Both companies propose to use Class 1 intermodal containers to transport wastes. Seaburn plans to use a barge with two horizontally mounted incinerators as the incineration vessel. The barge would carry approximately 144 5,000 gallon containers of wastes above deck. Oceanic Environmental proposes to use a conventional offshore supply vessel outfitted with one horizontally mounted incinerator. The vessel would carry approximately 80,000 gallons of wastes in 16 containers stored above deck. Each company proposes to use sea water scrubbers to cool incinerator off-gases and direct them into the ocean.

(1) CWM anticipates that demand for ocean incineration services in the Gulf area, if permitted, would be approximately 60,000 metric tons per year (even with an improved port facility); and

(2) Use of the throughput estimate for the existing facility allowed us to perform a sensitivity analysis examining the risks associated with use of intermediate waste storage at Emelle.

For both the land- and ocean-based systems, we have organized our analysis of release quantities by three or four components, respectively. As described in Chapter 1, these components include:

- Land Transportation: transport of wastes by truck from the generator site to the incinerator or pier;
- Transfer and Storage: transfer and storage operations at the land-based incinerator, pier or other storage facilities;
- Ocean Transportation: for the ocean-based system, transport of wastes by ship from the pier to the burn zone; and
- Incineration: incineration of the waste.

METHODS TO ESTIMATE QUANTITIES RELEASED

The releases from different system components vary from relatively unlikely releases of large quantities of waste (such as spills due to accidents involving tank trucks) to very likely releases of small quantities of waste (such as stack emissions, minor pump leaks, and so forth). In view of the stochastic nature of releases from many of these release points, the quantity of hazardous material released to the environment is likely to vary from year to year. Estimation of release quantities must take these variations into account.

Ideally, one would determine the probability of release for all possible release quantities at each release point. A probability distribution of potential releases could be developed for each release point and for the system as a whole. This distribution would indicate the likelihood of releases for all possible release quantities. Such distributions can be developed for only a few components of the land- and ocean-based systems. Thus, we develop estimates of the "expected value" of release -- the product of the probability of release and the average quantity released for each release point. In addition, for each point we estimate the probability that releasing events occur, the total quantity at risk (i.e., the maximum spill possible), and the average fraction of the quantity at risk released when an event occurs. For convenience, we use the following abbreviations and definitions throughout this report:

EN is the number of releasing events expected over a one year period, and is calculated from underlying probabilities of events multiplied by the level of activity projected over the year,

Q is the quantity at risk, for example the contents of one truck or one ship,

ERF is the expected release fraction if a releasing event occurs,

QR is the average quantity released if a releasing event occurs, and is the product of Q and ERF, and

EV is the expected value of release over a year, and is the product of EN and QR.

None of these single metrics is adequate to describe the underlying probability distribution of releases, but taken together they provide a more complete picture of the probabilities of release and quantities of hazardous material involved in the ocean- and land-based systems.

Releases from the incineration component of each system are continuous and certain to occur, although the magnitude of these releases is uncertain. We estimate both stack and fugitive losses of undestroyed wastes, products of incomplete combustion, metals included in the waste stream, and chlorine (in a variety of chemical forms). Our estimates of these quantities are based on our assumptions about waste composition and incinerator performance and on our analysis of trial burn data for land- and ocean-based incinerators.

To develop information on the probability and quantity of releases, we rely on many sources of information including past EPA and other studies, trade and academic literature, government datasets, and judgments from various experts. All specific sources are cited in the following chapters and appendices of this report. EPA contracted with Engineering Computer Optecnomics, Inc. (ECO) to provide information on vessel casualty rates and spill quantities; and with Arthur D. Little, Inc. (ADL) to provide information and analyses on releases from transfer and storage operations, and on the generation, composition and disposition of scrubber effluent at land-based incinerators. Dr. Jeff Kolb of EPA's Office of Policy Analysis developed information on comparable hazards as well as other data and insights useful in the study.

HUMAN AND ENVIRONMENTAL EFFECTS ANALYZED

The release of hazardous wastes and combustion by-products into the environment can cause a wide variety of effects. For purposes of discussion, we group the effects of major concern into four categories:

1. acute human health effects: effects caused by short-term exposure to hazardous releases or by explosions, fires and other accidental events;

2. chronic human health effects: effects caused by long-term exposure to hazardous releases;

3. acute environmental effects: damages to terrestrial and marine ecosystems due to short-term exposures to hazardous releases; and

4. chronic environmental effects: damages to terrestrial and marine ecosystems due to long-term exposures to hazardous releases.

Hazardous releases from land- and ocean-based incineration can be brought into contact with human and environmental populations through a number of pathways, many of which involve complex dispersion phenomena. The estimation of movement along these pathways and eventual human and environmental exposure is extremely difficult, particularly at long distances and for materials that are persistent and that bioconcentrate. Given current scientific knowledge it is not possible to fully and accurately predict the movement of hazardous materials once they are released from incineration systems. Further, data to allow accurate prediction of human health or environmental damage as a function of exposure to acute and chronic levels of hazardous materials are limited.

In view of these difficulties, we focus our efforts on those release points, environmental pathways and human and environmental effects we judge most important to the overall comparison of land- versus ocean-based incineration. Exhibit 2-1 illustrates all possible combinations of the four release points defined for incineration systems and the four types of human and environmental effects outlined above. As the exhibit shows, our major efforts concern the ocean transport and land- and ocean-based incineration release points.

As Exhibit 2-1 shows, we have not evaluated the effects resulting from land transportation releases. Since we have assumed land transportation release quantities would be the same for the land- and ocean-based systems, the resulting effects would be equivalent, on average, for the two systems.

We evaluate acute human health effects for the ocean transport release point, since inhalation of hazardous materials volatilized from spills could affect human health. Acute human health effects would not be expected from the other releases and resulting environmental concentrations, with the possible exception of land transportation accidents. However, acute effects such as injury or death could occur as a result of land or ocean transportation accidents, explosions or fires during transfer or storage operations, and so forth. We have not estimated the magnitude of these accidental injuries or deaths; in view of the low probabilities assigned to these events the expected effects would be very small. In addition, similar accidents would be expected (except for those involving ocean transportation) in both systems.

Our major efforts in transport and effects estimation concern the ocean transportation and land and ocean incineration release points. The dispersion of ocean transport spills and the resulting effects on the marine ecosystem are estimated for several spill locations and quantities. In addition, the bioconcentration of persistent compounds is estimated to provide information on contamination levels and as a proxy for marine chronic effects.

The releases from incineration itself occur continuously and with certainty rather than only in the (unlikely) event of an accident. We analyze the chronic human health effects expected due to inhalation from stack emissions and to ingestion of food contaminated by fallout from the stack plume. Further, we consider possible effects on the marine ecosystem from deposition of organic chemicals, metals and chlorine from the plume, and effects on the land ecosystem from the final disposal of scrubber effluent and sludge. We have not been able to consider the effects of land-based stack emissions on the terrestrial ecosystem due to limited time and resources. In addition to these major efforts, we evaluate the chronic human health effects expected from inhalation of fugitive releases from transfer and storage.

IEc used several methods to estimate pollutant transport and effects from ocean transportation releases and incinerator releases for both land- and ocean-based systems. First, we used EPA-developed air dispersion models and human health effects data to estimate the human health risks due to inhalation of hazardous materials released from land-based incinerators. In addition, we used recent EPA studies to estimate additional human health risks from ingestion of foodstuffs contaminated from incinerator stack emissions. Further, IEc subcontracted with Applied Science Associates, Inc. (ASA) to provide air dispersion analyses for the ocean-based incinerator; IEc used these estimates with EPA human health effects data to estimate human health risks from inhalation of ocean stack emissions.

For effects for ocean transportation releases, IEc subcontracted with ASA to provide ocean transport and ecosystem modeling for hypothetical spills at three sites: Mobile Harbor, over the continental shelf on the ship's path to the burn zone, and in the burn zone itself. Along with ASA's results, IEc calculated the possible human health effects from marine spills due to spill volatilization and subsequent human inhalation.

UNCERTAINTY

Our estimates of release from land- and ocean-based incineration systems and the resulting human and environmental effects are highly uncertain. In view of this uncertainty, it is useful to consider how these results should be interpreted and whether they represent typical or "worst-case" outcomes. These issues are discussed in the paragraphs below.

In conducting this analysis, we have structured system components and waste streams which are roughly typical of ocean- and land-based incineration. We have not located or configured either system in a manner which would yield worst or best case releases or effects. In addition, we have not assumed the worst or best possible waste compositions. In short, the systems and wastes analyzed are typical or average representations.

In estimating release probabilities and quantities, we often were forced to use data not directly applicable to the incineration system as structured. For example, in considering land transportation releases we assumed a vehicle accident rate similar to those experienced by tank trucks, and for ocean transport our accident rates are estimated by adjusting historical rates for tank ships to account for the design and operating characteristics of the Vulcanus, rather than by relying on the operating record of incinerator ships. Use of such data was necessary since adequate information for incinerator systems does not yet exist.

When specific information for transportation and handling was not available, we selected other data conservatively. As a result, we err on the side of overestimating release quantities and probabilities. With the exception of releases from ocean transport, this overestimation error is the same for both systems and thus does not effect the evaluation of comparative risk. The likely overestimate of ocean transport releases could bias the analysis against the ocean-based system; however, these estimated releases are a small portion of the expected long-term release from the incineration systems.

Our estimates of the releases from incineration itself are driven by our assumption about waste composition and incinerator performance (undestroyed waste, metals, chlorine) and by our analysis of trial burn data (PICs). Our estimates of PIC emissions are extremely uncertain and could well be biased to the low side. It is not possible to judge whether the extent of this bias, as well as the overall uncertainty, are similar for the two systems considered, and thus our PIC estimates could strongly affect the comparative risk assessment.

Available methods to estimate the dispersion of and effects from releases of hazardous substances generally use conservative methods. For example, both atmospheric and ocean dispersion models rely on simplified representations of winds, currents and other physical phenomena. This results in overestimation of concentrations, especially at longer distances. Further, coefficients developed to predict human or environmental damage as a function of exposure or dose are often calculated at the 95 percent confidence interval and assume all of the compound is biologically active. As a result, these dose-response factors overestimate the actual effects likely from a given level of exposure.

It is very difficult to consider all dispersion pathways and effects for compounds that persist in the environment and which bioaccumulate. For these compounds, available methods may overestimate the effects considered while ignoring other effects that occur at longer times and distances. If these latter effects are important, our analysis may underestimate the total eventual effects of such compounds.

In general, we have tried to use equally conservative data and methods to estimate effects from land- and ocean-based systems in order to generate comparable estimates. However, precise data on the likely uncertainty in these estimates are not available. Further, as explained previously, we were not able to look at all possible effects for both systems. In particular, limited time and resources precluded consideration of possible effects of releases from either incineration system on the terrestrial ecosystem.

As a result of these factors, we believe that while the incineration systems considered are structured to be "average", our estimates of release quantities and resulting effects are biased to the high side. We have tried to be consistent in our choice of methods and assumptions used to analyze each system, and thus the differences shown between systems are less uncertain and less biased. The purpose of this study is comparative assessment of ocean- versus land-based incineration systems. The validity of this comparison will be most strongly affected by methods or assumptions (such as PIC rates, scrubber efficiency) that change the relative performance of the systems.

SUMMARY

This chapter has reviewed the measures, analytic methods and general sources of data used in the study. In addition, the text above provides further information on the assumed structure of the incineration systems and on the sources, directions and magnitudes of uncertainty in our results.

Exhibit 2-1

POSSIBLE EFFECTS EVALUATED IN THE ANALYSIS

Release Point	Human Effects		Environmental Effects	
	Acute	Chronic	Acute	Chronic
Land Transportation	None Considered	None Considered	None Considered	None Considered
Transfer and Storage	None Considered	Effects from fugitive releases	None Considered	None Considered
Ocean Transportation	Effects from volatilization of spills	None Considered	Effects on biomass levels	Effects on bioconcentration levels (proxy)
Incineration	None Considered	Effects from inhalation of releases, ingestion of tainted foods	Effects from deposition of releases (ocean) and disposal of scrubber effluent/sludge (land)	Effects on marine bioconcentration levels (proxy)

WASTE QUANTITIES RELEASED FROM LAND TRANSPORTATION

CHAPTER 3

The analysis of releases from land transportation considers two types of potential losses -- vehicular accidents and enroute container failures from causes such as loose fittings, corrosion or internal pressure. Both of these events are probabilistic in nature. We base our estimates of potential releases from such events on existing studies of accident and failure rates and available information on the size distribution of the resulting spills. Using these data, we calculate the expected number of annual releases, the average quantity of waste released given a spill, and the expected annual release quantity. Below we discuss our sources of data, our assumptions, and characterize the resulting releases. Final sections of the chapter review the limitations of our estimates and compare our results with likely releases from general commerce.

DATA SOURCES

The analysis of releases from land transportation is based on several sources of information. Data concerning the frequency of vehicular accidents and container failures were provided by the U.S. Department of Transportation (DOT). Information on the size of release (the percentage of total truck cargo discharged in the event of an accident) was developed using DOT's Hazardous Materials Incident File (HAZMAT). Using this information we estimate annual releases for trucks transporting hazardous wastes from waste generators to CWM's proposed Chickasaw, Alabama port facility or to a land-based hazardous waste incinerator.

ASSUMPTIONS

The analysis of releases from transporting wastes on land is based on the following assumptions:

- Wastes are transported in 5000 gallon tank trucks;
- In the ocean-based case, the trucks carry wastes an average of 250 miles from the generator to CWM's proposed Chickasaw port facility; in the land-based case, the trucks travel 250 miles from the generator to a commercial land-based incinerator;
- All other conditions (for example, speed, highway composition, road surface, weather, traffic volume, share of day and night travel) are average.

It is important to emphasize that we assume equal trip distances for the land- and ocean-based systems. Although the average distance from generators to the transfer stations serving land- and ocean-based incineration may differ, analysis of typical trip distances is beyond the scope of the present study. A study of trip distances would require information on the location of generators, land-based incinerators, and future ocean-based facilities, as well as data on the capacity of each facility and the demand for incineration services.

To examine the effect of differing trip distances, we perform a sensitivity analysis assuming waste storage capacity does not exist at the port. In this case, we assume wastes would be trucked 250 miles to CWM's existing storage facility in Emelle, Alabama, stored there, and later transported 150 miles to Chickasaw for immediate loading onto the Vulcanus. This scenario increases the total trip distance in the ocean-based case from 250 to 400 miles.1/

1/CWM currently plans to construct storage tanks at Chickasaw. The company may be prohibited from doing so, however, if the tanks would be located in a floodplain. If the Vulcanus is permitted before storage tanks are constructed, CWM plans to use its Emelle facility as an intermediate storage site.

RELEASES FROM VEHICULAR ACCIDENTS

According to DOT's Bureau of Motor Carrier Safety, trucks are involved in enroute vehicular accidents at a rate of about 1.2 accidents per million miles traveled. About 29 percent of accidents involving tank trucks result in a release of cargo.2/ Therefore, we estimate the rate of releasing vehicular accidents for tank trucks to be 0.35 per million miles traveled (0.29 releases per accident x 1.2 accidents per million miles).

We base our analysis of releases from vehicular accidents on this accident rate, assuming that trucks that transport hazardous wastes at worst experience the same release rate from vehicular accidents as estimated for tank trucks. This assumption and alternative estimates of releasing vehicular accident rates are discussed later in this chapter.

Frequency of Vehicular Accidents

Given a releasing accident rate of 0.35 per million miles traveled, the expected number of releasing accidents is a function of the total number of miles traveled to deliver wastes from the generator to Chickasaw or to the land-based incinerator. In turn, this is a function of route length and the number of shipments required to deliver the annual quantity of waste incinerated.

Exhibit 3-1 summarizes the calculations used to estimate the number of shipments required to transport 56,000 metric tons of PCB wastes or 68,400 metric tons of EDC wastes. As the exhibit shows, 151 shipments of PCB wastes would be required for each voyage of the Vulcanus. Assuming 14 voyages per year for the PCB waste (see Appendix A), 2,114 truckloads are required to deliver the 56,000 MT annual throughput. More shipments (2,934) are required to deliver the EDC waste each year, due to the larger annual throughput and the lower density of the waste.

2/Derived from a memorandum from J. Nalevanko, Materials Transportation Bureau, Research and Special Programs Administration, Department of Transportation, to Dr. Jeff Kolb, EPA, 30 January 1985.

Exhibit 3-2 uses the above estimates to calculate the expected number of vehicular accidents per year for the PCB and EDC cases, assuming each shipment travels 250 miles. In the PCB case, the total distance traveled is 528,500 miles annually. At a releasing accident rate of 0.35 per million miles, the expected number of releasing vehicular accidents is 0.18 per year. The expected number of vehicular accidents in the EDC case is about 0.26 per year, higher than the PCB case due to the greater number of shipments and greater total distance traveled.

Waste Quantities
Released from Vehicular Accidents

Using HAZMAT data on the quantity of truck cargo lost in releasing vehicular accidents, we estimate the fraction of total cargo expected to be spilled if a releasing accident occurs. The HAZMAT data give the following distribution of release fractions.

Table 3-1
Quantity Released in a Releasing Truck Accident

Percent of Capacity Released	Percent of Releases
0-10%	31.6%
10-30%	18.7
30-50%	13.3
50-70%	9.8
70-90%	11.9
90-100%	14.7

Source: HAZMAT

These data indicate that over 30 percent of releasing vehicular accidents involve less than 10 percent of the total cargo. However, 14.7 percent of releasing vehicular accidents involve over 90 percent of the total cargo. The bimodal nature of the distribution indicates that accidents tend to be either minor or severe enough to cause a substantial loss of cargo. The average (or expected) release is approximately 39.5 percent of total cargo.

Exhibit 3-3 shows the calculation of the expected annual release from vehicular accidents for both the PCB and EDC cases. These calculations are based on the quantity of cargo at risk, the expected release fraction, and the expected number of annual releasing accidents. The average release quantity for PCB wastes is 10.5 metric tons, while the average release quantity for EDC wastes is 9.2 metric tons. The expected annual release is 1.9 metric tons and 2.4 metric tons in the PCB case and EDC case, respectively.

RELEASES FROM CONTAINER FAILURES

Frequency of Container Failures

The DOT data indicate that tank trucks transporting hazardous wastes will experience enroute container failures from causes other than vehicular accidents at a rate of about 0.43 per million miles traveled. Again, the expected number of container failures per year experienced by trucks carrying wastes is a function of the total number of miles traveled to deliver the waste from the generator to Chickasaw or to a land-based incinerator. Exhibit 3-4 shows the expected number of enroute container failures is 0.23 per year in the PCB case and 0.32 in the EDC case. The rate of release for EDC is greater than for PCBs due to the greater number of miles driven.

Waste Quantities Released from Container Failures

As with vehicular accidents, we use the HAZMAT data on the quantity of truck cargo lost in the event of a container failure to estimate the fraction of total cargo spilled. The data indicate the following distribution.

Table 3-2
Quantity Released from Container Failure

Percent of Capacity Released	Percent of Releases
0-10%	92.6%
10-20%	3.3
20-50%	2.0
50-100%	2.1

Source: HAZMAT

These data indicate that over 90 percent of enroute container failures release less than 10 percent of the cargo. The average release is approximately 4 percent of total cargo.

Exhibit 3-5 shows the calculation of the expected annual release from enroute container failures for the PCB and EDC cases. The expected annual release in the PCB case is approximately 0.25 metric tons; and the expected annual release in the EDC case is 0.29 metric tons.

CAVEATS AND SENSITIVITY ANALYSIS

Vehicular Accident Rate

The accident rate for trucks transporting hazardous wastes could be lower than the rates estimated from DOT data for several reasons.

1. The DOT data include trucks with aluminum tanks. Trucks carrying wastes to Chickasaw or to a land-based incinerator will have stainless steel tanks, making them more resistant to puncture or rupture.

2. CWM plans to hire only experienced drivers, provide special safety training, and take other precautions to avoid accidents. These measures should help reduce the likelihood that CWM trucks will be involved in vehicular accidents.

3. Data from several commercial waste management firms indicate an average accident rate (releasing and non-releasing) for all cargo vehicles operated by these companies of about 0.8 per million miles. This estimate is based on about 24 million vehicle miles of travel. Additionally, no releases of hazardous wastes from tank trucks due to accidents or container failures were experienced in approximately 9 million miles of travel. These accident and release rates are significantly lower, at the 95 percent confidence level, than the rates used in our analysis. We infer from this that trucks transporting hazardous wastes are less likely than other trucks to be involved in releasing accidents.3/

In light of these considerations, we believe our estimates of vehicular accident rates are higher than the actual accident rate for tank trucks that carry hazardous wastes. Any change in the assumed accident rate will have a proportional effect on the the estimated release quantities.

Trip Distance and the Potential Effect of Intermediate Waste Storage at Emelle

A second factor affecting the analysis of releases from land transport is the assumption that each shipment travels 250 miles. The accident and container failure rates are expressed on an incidents-per-mile basis. Therefore, estimates of both the expected number of releases and the expected annual release quantity are linearly related to the trip length assumed. Given this relationship, alternative trip distances would proportionally affect expected annual release estimates.

To illustrate this effect, we recalculate the expected number of releasing accidents and container failures per year and the annual expected release quantity for the land transportation component of the ocean-based incineration system, assuming that wastes are stored at CWM's Emelle storage facility rather than at

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3/Memorandum from Dr. Jeff Kolb (EPA) to Michael Huguenin (IEc), "Transportation Data from Companies in the Hazardous Waste Business," 24 September 1984.

a newly-built storage facility in Chickasaw. As noted previously, we assume that this arrangement adds 150 miles to the average trip distance for each shipment of waste, raising the total trip distance from 250 to 400 miles. The results are shown in Exhibit 3-6.

As this exhibit shows, the total distance traveled increases to 845,600 miles and over one million miles for the PCB case and the EDC case, respectively. The expected number of releasing accidents per year is about 0.30 in the PCB case and 0.41 in the EDC case, with expected annual releases of 3.14 MT of PCB waste and 3.79 MT of EDC waste. The expected number of enroute container failures per year is about 0.36 in the PCB case and 0.50 in the EDC case, with expected annual releases of 0.38 MT of PCB waste and 0.47 MT of EDC waste. These figures are about 60 percent greater than the expected releases in our baseline analysis, reflecting the increase in miles traveled.

Effect of Remedial Action

As a final point, we note that most commercial hazardous waste management firms maintain spill response teams trained to control and remove wastes released in vehicular accidents or as the result of container failures. Remedial action will reduce the quantity of waste ultimately released to the environment, and help to control the hazards presented by spills.

COMPARABLE HAZARDS

To compare the magnitude of possible releases from transporting hazardous wastes to releases from the transport of hazardous materials in daily commerce, we examined data on releases of hazardous substances maintained by the U.S. EPA's National Response Center (NRC).4/ According to the NRC, there were 67 transportation-related hazardous substance releases in EPA Region IV (an eight-state area of the southeastern U.S. that includes Alabama) in the last seven months of 1982.

4/The NRC data were reported in ICF, Inc., Release of High Production Volume Substances, April 1983. These data are adjusted to remove petroleum and petroleum product spills, and include only CERCLA-designated hazardous substances.

Extrapolating these data to a full year suggests 115 transportation-related hazardous substance releases would occur. The expected number of vehicular accidents and enroute container failures involving trucks serving a land- or ocean-based incineration system (0.41 per year in the PCB case and 0.58 per year in the EDC case) would represent about 0.5 percent of the estimated number of transportation-related releases of hazardous substances reported to the NRC for Region IV.

SUMMARY OF RELEASES FROM LAND TRANSPORTATION

Exhibit 3-7 summarizes the total expected annual release quantities from the land transportation component of a land-based and ocean-based incineration system. If hazardous waste generators are on average equidistant from the waste transfer stations serving land- and ocean-based incinerators, the expected releases from the land transportation components of the two systems are equal. As shown in this exhibit, the expected annual releases are 2.1 MT for the PCB waste and 2.7 MT for the EDC waste. The expected annual release from vehicular accidents is about eight times the expected annual release from container failures, despite the projection that slightly more releasing container failures are likely to occur. The larger expected release from vehicular accidents reflects the greater probability that these events release a significant fraction of total truck cargo.

Releases from the land transportation component of a land-based or ocean-based incineration system can occur relatively frequently. In the PCB case, an average of about 0.18 releasing accidents and 0.23 container failures are expected per year. In the EDC case, an annual average of about 0.26 releasing accidents and 0.32 container failures are expected. However, many of these releases would involve only a small quantity of waste. Almost 93 percent of enroute container failures are expected to release less than ten percent of the total cargo. The release quantities associated with vehicular accidents are larger, but 32 percent of such incidents are expected to release less than ten percent of a waste shipment.

Despite the expectation that the total release from trucks transporting wastes will be small, there is still a possibility that a significant release will occur. For example, we estimate that there is about a 0.09 probability that a truck transporting

EDC wastes will be involved in a vehicular accident that releases more than 50 percent of its 23.4 metric ton cargo during any particular year. Thus, it is important to bear in mind that releases during any single year could be significantly greater than the expected annual release quantity.

If transportation distances for the land- and ocean-based systems differ, expected annual releases from land transportation will also differ. This effect is illustrated by the analysis of releases should CWM store wastes in Emelle rather than Chickasaw. The 60 percent increase in transport distances associated with this arrangement would increase expected annual releases for the land transportation component of the ocean-based system by a corresponding percentage. Even in this case, however, the expected number of releasing incidents involving tank trucks serving an incineration system represents less than one percent of the transportation-related releases of hazardous substances currently reported for EPA Region IV.

Finally, available data for the hazardous waste management industry indicate a relatively low frequency of releasing accidents. These data suggest that our calculation of expected releases is conservative and probably overstates the quantity of waste released from land transportation.

Exhibit 3-1

CALCULATION OF NUMBER OF SHIPMENTS REQUIRED FOR TANK TRUCKS DELIVERING PCB OR EDC WASTES

Assumptions:

	PCB Waste	EDC Waste
Truck capacity (gallons)	5,000	5,000
Specific gravity	1.4000	1.2351
Ship capacity (metric tons, MT)	4,000	3,800
Voyages per year	14	18

Calculations: PCB Case

Cargo weight (MT) = 5,000 gallons x 3.785 liters/gallon * 1.4 kilograms/liter * 10E-3 MT/kilogram
= 26.5

Truckloads per voyage = 4,000 MT per voyage/26.5 MT per truckload
= 151

Truckloads per year = 151 truckloads per voyage * 14 voyages per year
= 2,114

Calculations: EDC Case

Cargo weight (MT) = 5,000 gallons * 3.785 liters/gallon * 1.2351 kilograms/liter * 10E-3 MT/kilogram
= 23.4

Truckloads per voyage = 3,800 MT per voyage/23.4 MT per truckload
= 163

Truckloads per year = 163 truckloads per voyage * 18 voyages per year
= 2,934

Source: IEc Analysis

Exhibit 3-2

CALCULATION OF EXPECTED NUMBER (EN) OF RELEASING VEHICULAR ACCIDENTS PER YEAR FOR TANK TRUCKS SERVING LAND- OR OCEAN-BASED INCINERATION SYSTEMS

Assumptions:

	PCB Waste	EDC Waste
Truckloads per year	2,114	2,934
Trip length (miles)	250	250
Incident rate (IR) (releasing accidents/mile)	3.5E-7	3.5E-7

Calculations: PCB Case

Annual Involvement (AI) = 2,114 truckloads/year * 250 miles/truckload
= 528,500 miles/year

EN = AI * IR
= 528,500 miles/year * 3.5E-7 releasing accidents/mile
= 0.18 releasing accidents/year

Calculations: EDC Case

AI = 2,934 truckloads/year * 250 miles/truckload
= 733,500 miles/year

EN = 733,500 miles/year * 3.5E-7 releasing accidents/mile
= 0.26 releasing accidents/year

Source: IEc Analysis

Exhibit 3-3

CALCULATION OF EXPECTED ANNUAL RELEASE (EV) FROM VEHICULAR ACCIDENTS FOR TRUCKS SERVING LAND- OR OCEAN-BASED INCINERATION SYSTEMS

PCB Waste

Assumptions:

Expected release fraction (ERF) = 0.395
Quantity at risk (Q) = 26.5 MT
Expected number of releases per year (EN) = 0.18

Calculations:

Average quantity released (QR) = Q * ERF
= 26.5 MT * 0.395
= 10.4675 MT

EV = QR * EN
= 10.5 MT * 0.18
= 1.89 MT

EDC Waste

Assumptions:

ERF = 0.395
Q = 23.4 MT
EN = 0.26

Calculations:

QR = Q * ERF
= 23.4 * 0.395
= 9.243 MT

EV = QR * EN
= 9.2 MT * 0.26
= 2.39 MT

Source: IEc Analysis

Exhibit 3-4

CALCULATION OF EXPECTED NUMBER (EN) OF ENROUTE CONTAINER FAILURES PER YEAR FOR TANK TRUCKS SERVING LAND- OR OCEAN-BASED INCINERATION SYSTEMS

PCB Waste

Assumptions:

Annual involvement (AI) = 528,500 miles/year
Incident rate (IR) = 4.3E-7 container failures/mile

Calculation:

EN = AI * IR

= 528,500 miles/year * 4.3E-7 container failures/mile

= 0.23 container failures/year

EDC Waste

Assumptions:

AI = 733,500 miles/year
IR = 4.3E-7 container failures/mile

Calculation:

EN = AI * IR

= 733,500 miles/year * 4.3E-7 container failures/mile

= 0.32 container failures per year

Source: IEc Analysis

Exhibit 3-5

CALCULATION OF EXPECTED ANNUAL RELEASE (EV) FROM ENROUTE CONTAINER FAILURES FOR TRUCKS SERVING LAND- OR OCEAN-BASED INCINERATION SYSTEMS

PCB Waste

Assumptions:

Expected release fraction (ERF) = 0.04
Quantity at risk (Q) = 26.5 MT
Expected number of releases per year (EN) = 0.23

Calculations:

Average quantity released (QR) = Q * ERF

= 26.5 MT * 0.04

= 1.06 MT

EV = QR * EN

= 1.1 MT * 0.23

= 0.25 MT

EDC Waste

Assumptions:

ERF = 0.04
Q = 23.4
EN = 0.32

Calculations:

QR = Q * ERF

= 23.4 MT * 0.04

= 0.936 MT

EV = QR * EN

= 0 .9 MT * 0.32

= 0.29 MT

Source: IEc Analysis

Exhibit 3-6

EFFECT OF STORAGE AT EMELLE, ALABAMA ON EXPECTED RELEASE QUANTITIES IN THE OCEAN-BASED INCINERATION SYSTEM

Assumptions	PCB Waste	EDC Waste
Truckloads per year	2,114	2,934
Trip length (miles)	400	400
Quantity at risk (MT)	26.5	23.4
Releasing accident rate	3.5E-7	3.5E-7
Container failure rate	4.3E-7	4.3E-7
Fraction released in event of accident	0.395	0.395
Fraction released in event of container failure	0.04	0.04
Calculations		
Total miles traveled	845,600	1,173,600
Expected number of releasing accidents per year	0.30	0.41
Expected number of container failures per year	0.36	0.50
Annual expected release from accident (MT)	3.14	3.79
Annual expected release from container failure (MT)	0.38	0.47

Source: IEc Analysis

Exhibit 3-7

SUMMARY OF EXPECTED RELEASES FROM LAND TRANSPORTATION

	PCB Waste	EDC Waste
Expected Number of Releasing Incidents:		
Vehicular Accidents	0.18	0.26
Container Failures	0.23	0.32
Annual Quantity Released (MT):		
Vehicular Accidents	1.89	2.39
Container Failures	0.25	0.29
Total Release	2.14	2.68

Source: IEc Analysis

RELEASES FROM WASTE TRANSFER AND STORAGE

CHAPTER 4

This chapter describes our analysis of releases during transfer and storage of wastes for both ocean- and land-based incineration systems. The analysis considers three sources of releases -- spills when transferring wastes to and from tank trucks, spills from equipment at waste transfer and storage facilities, and fugitive emissions from transfer and storage. Fugitive emissions are slow leaks from pump fittings, sampling connections, flanges, storage tanks and other equipment. Some of these releases are probabilistic, while others are relatively certain.

The following discussion describes our data sources and assumptions and the resulting estimates of waste release quantities for these three sources. This chapter also includes a sensitivity analysis examining releases from transfer and storage should CWM not build storage tanks at its port facility.

DATA SOURCES

The analysis of storage and transfer releases is based on several sources. Data on release rates during truck loading and unloading operations are based on data supplied by DOT, as cited in Chapter 3. Information on the quantity of waste likely to be released in the event of such spills was obtained from the HAZMAT file, also described in Chapter 3. Arthur D. Little, Inc. (ADL) analyzed spills and fugitive emissions at storage and transfer sites. Appendix B summarizes the ADL analysis of these releases.[1]

ASSUMPTIONS

The analysis of waste releases during transfer and storage is based on operation of the facility that CWM proposes to build at its port in Chickasaw. We assume that similar transfer and storage equipment is located at the land-based incinerator. Appendix B gives a full description of the probable configuration of this facility.

We also consider storage of waste at Emelle, rather than at Chickasaw. This analysis considers the following sources of releases:

- Spills when unloading and loading tank trucks at Emelle and when unloading at Chickasaw;
- Spills from transfer and storage equipment at Emelle and for transfer equipment at Chickasaw; and
- Fugitive emissions from all equipment at both Emelle and Chickasaw.

As this list suggests, intermediate waste storage at Emelle adds several potential release points to the ocean-based incineration system.

TRANSFERS TO AND FROM TANK TRUCKS

Frequency of Loading/Unloading Spills

The DOT data provide information on the rate at which spills at transportation terminals occur. The data indicate that releases involving the loading and unloading of tank trucks occur at a rate of 1.7 per hundred thousand handlings. Thus, the number of handlings involved in delivering waste to Chickasaw or to a land-based incinerator will determine the probability of a transfer release in a given year.

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[1] We used the DOT and HAZMAT data rather than the ADL analysis to describe releases from loading and unloading tank trucks because the ADL analysis is limited to releases from loading/unloading arm failures, and does not consider other potential causes of loading/unloading spills.

The assumptions for land transport given in Exhibit 3-1 of Chapter 3 yield the following estimates of the number of shipments required to deliver annual throughput quantities to Chickasaw or to a land-based incinerator.

- o PCB wastes: 2,114 shipments of approximately 26.5 MT each;
- o EDC wastes: 2,934 shipments of approximately 23.4 MT each.

Each shipment must be unloaded at the termination of the trip. (The original loading of the tank truck is excluded in our analysis since this step occurs at the generator site.)

Based on these estimates, Exhibit 4-1 shows calculation of the expected number of transfer spills in the PCB and EDC cases for both ocean- and land-based incinerators. In the PCB case, the expected number of spills is 0.04 per year. In the EDC case, the expected number of transfer spills is 0.05 per year. The slightly higher chance of a spill in the EDC case is a result of the greater number of handlings required.

Waste Quantities Released from Truck Unloading Spills

HAZMAT data on the fraction of cargo lost in the event of a transfer release suggest the following distribution of release fractions.

Table 4-1
Quantity Released from Tranfer Operations

Percent of Capacity Released	Percent of Releases
0-10%	94.4%
10-20%	2.9
20-50%	2.0
50-100%	0.7

Source: HAZMAT

These data indicate that over 94 percent of transfer spills release less than 10 percent of the cargo. Less than one percent involve 50 to 100 percent of the total load. The HAZMAT data show that the average fraction released is approximately 3 percent.

Exhibit 4-2 illustrates the calculation of the expected quantity of waste released while loading and unloading tank trucks. The expected release quantity in the event PCB wastes are spilled is 0.8 metric tons. In the EDC case, the expected release quantity is 0.7 metric tons. Over a year the expected release is approximately 0.03 metric tons in both the PCB and EDC cases.

SPILLS AT TRANSFER AND STORAGE FACILITIES

Appendix B describes CWM's "improved" Chickasaw waste storage and transfer facility and the storage and transfer facility assumed for the land-based incinerator. The analysis of the potential for spills at each site based on available failure rate data for valves, pipes, loading hoses, and liquid storage tanks also is provided in Appendix B. The results of this analysis are summarized below.

Frequency of Spills at Transfer and Storage Facilities

Exhibit 4-3 summarizes the expected number of releases per year for the storage and transfer facilities at ocean-based and land-based systems (exclusive of spills from unloading trucks). As the exhibit indicates, the total expected number of releases from all storage and transfer components of the ocean-based system is 0.03 per year in the PCB case and 0.04 per year in the EDC case. The total expected number of releases from the land-based storage and transfer facility is approximately 0.04 for both the PCB and EDC cases. The frequency of failures is slightly higher for the land-based system since we assume the pumps and pipelines at the land-based facility constantly contain wastes, whereas approximately half of the pumps and pipelines for the sea-based system (those required for vessel loading) are assumed to carry wastes only during the 36-hour period required to load the incinerator ship.

As shown, the ocean-based system has one additional component -- the loading hose used to transfer wastes to the ship. We estimate the probability of a spill from the hose to be roughly two to three in one-thousand per year.

Pump failures are the single most likely cause of a release at both Chickasaw and the land-based incinerator, with the total expected number of releases from such failures ranging from .02 to .03 per year. In contrast, the least likely sources of a release are the two 800 thousand gallon waste storage tanks at each site. For each system, the expected number of spills from these tanks is 2.0E-4 per year, a long-term average of one spill every 5,000 years.

Waste Quantities Released from Spills at Transfer and Storage Facilities

Exhibits 4-4 and 4-5 present the average spill quantities for each component of the storage and transfer networks for PCB and EDC wastes, respectively. The exhibits also show the expected annual release quantity for each component using the frequency of spills from Exhibit 4-3. The exhibits indicate that the expected annual release at storage and transfer facilities for either ocean- or land-based incineration systems is approximately 0.5 metric tons in both the PCB and EDC cases. In each case, releases from storage tanks account for roughly 80 percent of the expected annual release. While a storage tank failure is expected to occur only once in 5,000 years, the expected release in the event of a failure is so large (1,870 to 2,115 metric tons) that this low probability, high release event dominates the total expected annual release for both systems.2/ Again, the expected annual release from the land-based system is slightly larger than the expected annual release for the ocean-based system because of the greater likelihood of releases from valves and pipelines at the land-based operation.

2/According to Appendix B, ADL's estimates of the probability of a storage tank failure and the quantity of waste released in the event of a failure apply to "catastrophic" releases. Minor releases are not significant and are ignored.

FUGITIVE EMISSIONS FROM TRANSFER AND STORAGE FACILITIES

In addition to hazardous waste spills, storage and transfer facilities are sources of airborne fugitive emissions. As described in Appendix B, intermittent fugitive emissions at Chickasaw or the land-based incinerator are associated with occasional small leaks from pumps and valves in the waste storage and transfer network. Relatively continuous sources of fugitive emissions include ordinary breathing losses from storage tanks, working losses that occur in filling and emptying tanks, and activities such as manual gaging of tank truck cargo levels.

Exhibit 4-6 summarizes expected annual fugitive emissions for the improved Chickasaw facility and for the land-based incineration site. As the exhibit shows, expected fugitive emissions for the ocean-based system are approximately 0.7 metric tons per year in both the PCB and EDC cases. In comparison, expected fugitive emissions for the land-based system are 0.6 metric tons per year for both wastes. Fugitive releases are slightly higher for the ocean-based system due to the emissions associated with loading the incinerator ship's cargo tanks. Otherwise, fugitive emissions from the transfer and storage facilities are identical. Emissions from storage tanks dominate total fugitive emissions in both cases, accounting for approximately two-thirds of total releases for the ocean-based system and 80 percent of total releases for the land-based operation.3/

CAVEATS AND SENSITIVITY ANALYSIS

Releases from an Ocean-Based System Assuming Intermediate Storage at Emelle

As described in Chapter 3, CWM would store wastes at its Emelle, Alabama storage facility if development of waste storage capacity at Chickasaw is not feasible. This arrangement requires

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3/Note that the ADL analysis contained in Appendix B assumes the same vapor pressure for the PCB and EDC wastes, and therefore does not consider the effect that different volatilization rates could have on emissions from storage tanks.

tank trucks to unload wastes at Emelle, reload to deliver wastes to the Vulcanus, and unload again at the port. Tripling the number of truck loading/unloading steps in this manner triples the expected number and annual quantity of loading/unloading spills, as shown in Exhibit 4-7. The expected number of loading/unloading spills annually is 0.11 and 0.15 for the PCB and EDC wastes, respectively. The expected release quantity is 0.09 MT of PCB waste and 0.11 MT of EDC waste.

Intermediate waste storage at Emelle also would affect expected releases from storage and transfer equipment. Under this arrangement, the existing storage and transfer equipment at both Emelle and Chickasaw would be potential release sources. The expected number of releases from the various components of the two facilities is summarized in Exhibit 4-8. The exhibit indicates that the total number of releases expected for the two facilities is 0.07 per year in the PCB case and 0.08 per year in the EDC case, slightly more than double the expected number of releases in the baseline analysis of the ocean-based system. The higher number of releases is primarily due to a greater number of pump failures, since the combined Emelle/Chickasaw system requires more than twice as many pumps as an integrated port facility.

Exhibits 4-9 and 4-10 summarize expected release quantities for the Emelle/Chickasaw transfer and storage system for the PCB and EDC wastes, respectively. The expected quantity released, excluding storage tanks, is about 0.16 and 0.18 metric tons for the PCB and EDC wastes, respectively. These figures are about double those estimated for the improved Chickasaw facility. However, as the exhibits show, the expected total annual release in both cases is approximately 0.4 metric tons, 0.1 metric tons less than the release expected for the improved Chickasaw facility. The lower total release for the non-integrated facility is due to the assumption that wastes would be stored at Emelle in four 200 thousand gallon storage tanks rather than the two 800 thousand gallon tanks assumed for the integrated Chickasaw operation. This assumption reduces by half the total quantity of waste "at risk" in storage tanks at any point in time -- 800 thousand gallons at Emelle versus 1.6 million gallons at an integrated Chickasaw facility -- and therefore reduces by half the expected annual release from this source.[4]

Exhibit 4-11 illustrates expected annual fugitive emissions for the ocean-based incineration system, assuming that wastes are stored at Emelle. The exhibit indicates that fugitive emissions would total 4.9 metric tons per year in the PCB case and 5.5 metric tons per year in the EDC case. These estimates are more than seven times higher than the fugitive emission estimates made for an integrated Chickasaw facility. Fugitive emissions are considerably higher for storage at Emelle since ADL assumed the storage tanks at Emelle would have fixed roofs, as opposed to the tanks with floating internal covers assumed for the new Chickasaw operation. As explained in Appendix B, the use of floating covers minimizes vapor spaces and significantly reduces fugitive emissions.

Total expected annual releases for the Emelle/Chickasaw storage and transfer system are summarized below.

Table 4-2
Summary of Storage and Transfer Releases for
Emelle/Chickasaw Configuration

	PCB Waste (MT per year)	EDC Waste (MT per year)
Truck loading/ unloading spills	0.1	0.1
Spills at transfer/ storage facilities	0.4	0.4
Fugitive emissions	4.9	5.5
Total releases	5.4	6.0

Source: IEc Analysis

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[4] This assumption by ADL introduces a minor inconsistency in our analysis. Assuming that the improved port facility has twice the storage capacity implies that the wastes are held in storage for a longer period of time or that the tanks are only filled to half capacity compared to the Emelle storage facility.

The net effect of intermediate waste storage at Emelle rather than development of an integrated storage and port facility at Chickasaw is an increase in the expected annual releases for the storage and transfer component of an ocean-based incineration system from 1.2 metric tons to 5.4 metric tons in the PCB case and to 6.0 metric tons in the EDC case. Both cases present about a fivefold increase in releases from storage and transfer operations, and yield total releases about five times greater than that estimated for the land-based incineration system.

Effect of Remedial Action

It is important to note that hazardous waste transfer and storage facilities typically are equipped to contain most waste spills. For example, the existing storage tanks at Emelle are located in spill containment areas, and the existing waste transfer station in Chickasaw has a spill containment area. Spill containment equipment is also likely to be present at most land-based incineration facilities. These precautions limit the health and environmental effects from hazardous waste releases.

COMPARABLE HAZARDS

During the last seven months of 1982, 132 releases of hazardous substances occurred at "fixed facilities" (i.e., not vehicles) in EPA Region IV and were reported to the U.S. EPA's National Response Center.[5] Extrapolating over a full year, we estimate that 226 hazardous materials spills of this type would occur in Region IV. In contrast, the expected number of spills from the waste storage and transfer systems at Chickasaw or a land-based incinerator (including truck loading/unloading spills and spills from transfer and storage equipment) is approximately 0.1 in both the PCB and EDC cases. Thus, the expected number of spills from ocean- or land-based incinerator waste storage and transfer operations represents less than 0.1 percent of the region's reported fixed facility hazardous materials spills.

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[5] ICF, Inc., Releases of High Production Volume Substances, April 1983. As explained previously, these are CERCLA-designated hazardous substances.

Data to compare the total quantity of fugitive emissions from the ocean- and land-based incineration systems are unavailable. However, thirty waterfront facilities in the Port of Mobile currently are authorized to handle and/or store federally-designated hazardous materials.6/ The number of these facilities near Mobile suggests that other sources of hazardous fugitive emissions exist in the area.

SUMMARY OF STORAGE AND TRANSFER RELEASES

The estimated releases associated with the storage and transfer component of ocean- and land-based incineration systems are summarized in Exhibit 4-12. The summary does not distinguish between the PCB and EDC wastes since the expected release quantities (rounded to the nearest 100 kilograms) are identical. As this table indicates, expected annual releases from the ocean- and land-based systems differ only slightly, due to the higher level of fugitive emissions for the ocean-based alternative. The table also shows that spills and fugitive emissions are approximately equal sources of storage and transfer releases, each accounting for roughly half the expected annual storage and transfer losses in both the ocean- and land-based case.

As shown in our sensitivity analysis, these release estimates are very sensitive to the configuration of the storage/transfer facilities. If CWM stored wastes at Emelle rather than Chickasaw, the release quantities would be greatly increased, primarily due to fugitive emissions resulting from the use of fixed rather than floating roof storage tanks at the Emelle facility. Also, the expected number and quantity of truck loading/unloading spills would triple, as a result of tripling the number of handlings required.

Again, it is important to bear in mind that waste spills during any single year could be significantly greater than the expected annual release quantity. For example, a single storage tank failure could release approximately 2,000 metric tons of hazardous waste. However, the probability of such an event is extremely low -- about one in 5,000 per year.

6/Personal communication with Captain W.J. Ecker, U.S. Coast Guard, Captain of the Port, Mobile, Alabama.

Exhibit 4-1

CALCULATION OF EXPECTED NUMBER (EN) OF LOADING/UNLOADING SPILLS PER YEAR FOR TANK TRUCKS SERVING LAND- AND OCEAN-BASED INCINERATION SYSTEMS

PCB Waste

Assumptions:

Annual involvement (AI) = 2,114 transfers/year
Incident rate (IR) = 1.7E-5 spills/transfer

Calculation:

EN = AI * IR

= 2,114 transfers/year * 1.7E-5 spills/transfer

= 0.04 spills/year

EDC Waste

Assumptions:

AI = 2,934 transfers/year

IR = 1.7E-5 spills/transfer

Calculation:

EN = AI * IR

= 2,934 transfers/year * 1.7E-5 spills/transfer

= 0.05 spills/year

Source: IEc Analysis

Exhibit 4-2

CALCULATION OF EXPECTED ANNUAL RELEASE (EV) FROM UNLOADING SPILLS FOR TRUCKS SERVING LAND- OR OCEAN-BASED INCINERATION SYSTEMS

PCB Waste

Assumptions:

Expected release fraction (ERF) = 0.03
Quantity at risk (Q) = 26.5 MT
Expected number of releases per year (EN) = 0.04

Calculation:

Average quantity released (QR) = Q * ERF
= 26.5 MT * 0.03
= 0.795 MT

EV = QR * EN
= 0.8 MT * 0.04
= 0.032 MT

EDC Waste

Assumptions:

ERF = 0.03
Q = 23.4 MT
EN = 0.05

Calculation:

QR = Q * ERF
= 23.4 MT * 0.03
= 0.702 MT

EV = QR * EN
= 0.7 MT * 0.05
= 0.035 MT

Source: IEc Analysis

Exhibit 4-3

EXPECTED NUMBER OF SPILLS (EN) PER YEAR FOR WASTE TRANSFER AND STORAGE FACILITIES SERVING LAND- AND OCEAN-BASED INCINERATION SYSTEMS

Ocean-Based System-Improved Chickasaw Facility:

Component	Frequency for PCB Waste	Frequency for EDC Waste
Valves	4.8E-3	4.8E-3
Pipelines	4.2E-3	4.3E-3
Pumps	2.1E-2	2.7E-2
Loading Hose (ship)	2.0E-3	2.6E-3
Storage Tanks	2.0E-4	2.0E-4
Total	3.22E-2	3.98E-2

Land-Based System:

Component	Frequency for PCB Waste	Frequency for EDC Waste
Valves	8.9E-3	8.9E-3
Pipelines	6.7E-3	6.7E-3
Pumps	2.1E-2	2.7E-2
Storage Tanks	2.0E-4	2.0E-4
Total	3.7E-2	4.3E-2

Source: ADL Analysis, Appendix B.

Exhibit 4-4

EXPECTED RELEASE QUANTITIES FOR SPILLS AT WASTE TRANSFER AND STORAGE FACILITIES: PCB WASTE

Ocean-Based System -- Improved Chickasaw Facility:

Component	Spill Size (MT)	Expected Annual Release (MT)
Valves	3.4	1.63E-2
Pipelines	6.9	2.90E-2
Pumps	1.1	2.31E-2
Loading Hose (ship)	6.9	1.38E-2
Storage Tanks	2,114.6	4.23E-1
Total		5.05E-1

Land-Based System:

Component	Spill Size (MT)	Expected Annual Release (MT)
Valves	3.4	3.03E-2
Pipelines	6.9	4.62E-2
Pumps	1.1	2.31E-2
Storage Tanks	2,114.6	4.23E-1
Total		5.23E-1

Source: ADL Analysis, Appendix B.

Exhibit 4-5

EXPECTED RELEASE QUANTITIES FOR SPILLS AT WASTE TRANSFER AND STORAGE FACILITIES: EDC WASTE

Ocean-Based System -- Improved Chickasaw Facility:

Component	Spill Size (MT)	Expected Annual Release (MT)
Valves	3.0	1.44E-2
Pipelines	6.1	2.62E-2
Pumps	1.0	2.70E-2
Loading Hose (ship)	6.1	1.59E-2
Storage Tanks	1,869.8	3.74E-1
Total		4.58E-1

Land-Based System:

Component	Spill Size (MT)	Expected Annual Release (MT)
Valves	3.0	2.67E-2
Pipelines	6.1	4.09E-2
Pumps	1.0	2.70E-2
Storage Tanks	1,869.8	3.74E-1
Total		4.69E-1

Source: ADL Analysis, Appendix B.

Exhibit 4-6

EXPECTED ANNUAL FUGITIVE EMISSIONS FROM TRANSFER AND STORAGE FACILITIES

Ocean-Based System -- Improved Chickasaw Facility:

Source	PCB Waste Expected Emissions (MT/yr)	PCB Waste Percent of Total Emissions	EDC Waste Expected Emissions (MT/yr)	EDC Waste Percent of Total Emissions
Truck gaging	3.2E-2	4.8%	4.4E-2	6.1%
Pumps	3.0E-2	4.5	3.0E-2	4.2
Valves	4.2E-2	6.3	4.3E-2	6.0
Storage tanks	4.6E-1	68.7	4.7E-1	65.3
Ship cargo tanks	1.1E-1	16.4	1.4E-1	19.4
Total	6.7E-1	100.0%	7.2E-1	100.0%

Land-Based System:

Source	PCB Waste Expected Emissions (MT/yr)	PCB Waste Percent of Total Emissions	EDC Waste Expected Emissions (MT/yr)	EDC Waste Percent of Total Emissions
Truck gaging	3.2E-2	5.7%	4.4E-2	7.5%
Pumps	3.0E-2	5.3	3.0E-2	5.1
Valves	4.2E-2	7.4	4.3E-2	7.4
Storage tanks	4.6E-1	81.6	4.7E-1	80.0
Total	5.6E-1	100.0%	5.8E-1	100.0%

Note: Totals may not sum due to rounding.

Source: ADL Analysis, Appendix B.

Exhibit 4-7

EFFECT OF STORAGE FACILITY AT EMELLE ON TRUCK LOADING/UNLOADING RELEASES IN OCEAN-BASED INCINERATOR SYSTEM

	PCB Waste	EDC Waste
Annual Involvement (transfers/year)	6,342	8,802
Incident Rate	1.7E-5	1.7E-5
Expected Number of Releases	0.11	0.15
Quantity at Risk (MT)	26.5	23.4
Expected Release Fraction	0.03	0.03
Expected Quantity Released (MT)	0.09	0.11

Source: IEc Analysis

Exhibit 4-8

EXPECTED NUMBER OF SPILLS PER YEAR FROM UNIMPROVED WASTE TRANSFER AND STORAGE FACILITIES AT EMELLE AND CHICKASAW

	Component	Frequency for PCB Waste	Frequency for EDC Waste
Emelle:	Valves	7.9E-3	7.9E-3
	Pumps	3.0E-2	3.9E-2
	Storage Tanks	4.0E-4	4.0E-4
	Subtotal	3.83E-2	4.73E-2
Chickasaw:	Valves	1.4E-3	1.7E-3
	Pumps	1.5E-2	1.9E-2
	Pipelines	1.2E-3	1.5E-3
	Loading Hose	1.0E-2	1.3E-2
	Subtotal	2.76E-2	3.52E-2
Total:	Valves	9.3E-3	9.6E-3
	Pumps	4.5E-2	5.8E-2
	Pipelines	1.2E-3	1.5E-3
	Loading Hose	1.0E-2	1.3E-2
	Storage Tanks	4.0E-4	4.0E-4
	TOTAL	6.59E-2	8.25E-2

Source: ADL Analysis, Appendix B.

Exhibit 4-9

EXPECTED RELEASE QUANTITIES FOR SPILLS FROM UNIMPROVED WASTE TRANSFER AND STORAGE FACILITIES AT EMELLE AND CHICKASAW: PCB WASTE

	Component	Spill Size (MT)	Expected Annual Release (MT)
Emelle:	Valves	3.4	2.69E-2
	Pumps	1.1	3.30E-2
	Storage Tanks	529.9	2.12E-1
	Subtotal		2.72E-1
Chickasaw:	Valves	3.4	4.76E-3
	Pumps	1.1	1.65E-2
	Pipelines	6.9	8.28E-3
	Loading Hose	6.9	6.90E-2
	Subtotal		9.85E-2
Total:	Valves	3.4	3.16E-2
	Pumps	1.1	4.95E-2
	Pipelines	6.9	8.28E-3
	Loading Hose	6.9	6.90E-2
	Subtotal		1.59E-1
	Storage Tanks	529.9	2.12E-1
	TOTAL		3.70E-1

Source: ADL Analysis, Appendix B.

Exhibit 4-10

EXPECTED RELEASE QUANTITIES FOR SPILLS FROM UNIMPROVED WASTE TRANSFER AND STORAGE FACILITIES AT EMELLE AND CHICKASAW: EDC WASTE

	Component	Spill Size (MT)	Expected Annual Release (MT)
Emelle:	Valves	3.0	2.37E-2
	Pumps	1.0	3.90E-2
	Storage Tanks	467.4	1.87E-1
	Subtotal		2.50E-1
Chickasaw:	Valves	3.0	5.10E-3
	Pumps	1.0	1.90E-2
	Pipelines	6.1	9.15E-3
	Loading Hose	6.1	7.93E-2
	Subtotal		1.13E-1
Total:	Valves	3.0	2.88E-2
	Pumps	1.0	5.80E-2
	Pipelines	6.1	9.15E-3
	Loading Hose	6.1	7.93E-2
	Subtotal		1.75E-1
	Storage Tanks	467.4	1.87E-1
	TOTAL		3.62E-1

Source: ADL Analysis, Appendix B.

Exhibit 4-11

EXPECTED ANNUAL FUGITIVE EMISSIONS FROM UNIMPROVED WASTE TRANSFER AND STORAGE FACILITIES AT EMELLE AND CHICKASAW

		PCB Waste		EDC Waste	
	Source	Expected Emissions (MT/yr)	Percent of Total Emissions	Expected Emissions (MT/yr)	Percent of Total Emissions
Emelle:	Truck gaging	3.2E-2	0.7%	4.4E-2	0.8%
	Pumps	1.5E-2	0.3	1.5E-2	0.3
	Valves	8.0E-2	1.6	8.0E-2	1.5
	Storage tanks	4.0E+0	81.6	4.4E+0	80.0
	Truck loading	5.7E-1	11.6	7.3E-1	13.3
	Subtotal	4.7E+0	96.6	5.3E+0	96.2
Chickasaw:	Truck gaging	3.2E-2	0.7	4.4E-2	0.8
	Pumps	1.5E-2	0.3	1.5E-2	0.3
	Valves	1.1E-2	0.2	1.5E-2	0.3
	Ship cargo tanks	1.1E-1	2.2	1.4E-1	2.5
	Subtotal	1.7E-1	3.5	2.1E-1	3.8
TOTAL		4.9E+0	100.0%	5.5E+0	100.0%

Note: Totals may not sum due to rounding.

Source: ADL analysis, Appendix B.

Exhibit 4-12

EXPECTED RELEASES (EV) FROM STORAGE AND TRANSFER COMPONENT OF LAND-BASED AND OCEAN-BASED INCINERATOR SYSTEMS

Source	Ocean-Based	Land-Based
Truck Unloading/Loading Spills	-- *	-- *
Spills at Transfer/Storage Facilities	0.5	0.5
Fugitive Emissions	0.7	0.6
Total Quantity Released (MT)	1.2	1.1

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* Less than 0.05 MT

Source: IEc Analysis

WASTE RELEASES FROM OCEAN TRANSPORTATION

CHAPTER 5

The ocean transportation component of ocean-based incineration is the only major component of the system that has no parallel in a land-based operation. Therefore, potential releases from ocean transportation are of special interest when comparing the relative risks of land- and ocean-based incineration systems. These potential releases are discussed in this chapter.

DATA AND ASSUMPTIONS

The analysis of spills from the Vulcanus as a result of a vessel casualty is based on an analysis of vessel casualty rates and expected release quantities prepared by Engineering Computer Optecnomics, Inc. (ECO). This analysis, contained in Appendix C, groups vessel casualties into three impact categories (collisions, groundings and rammings) and one non-impact category (fires, explosions, structural failures, and capsizings). The analysis provides estimates of vessel casualties and resulting spills at four different locations:

- Mobile Harbor and the Vulcanus' pier in Chickasaw;
- Mobile Bay;
- The Gulf coastal area; and
- The burn zone.

All estimates are based on a proprietary, worldwide tank ship accident and spill database (entitled ECOTANK) that is maintained by ECO. This database presently contains information about 10,000 worldwide tank ship accidents and over 1,000 tank ship spill events that occurred from 1969 to 1982. As described in Appendix C and later in this chapter, ECO has adjusted these spill rate estimates to account for the design and operation of the Vulcanus.

Incinerator ships have operated off the European coast in the North Sea since 1972. They have made about 320 voyages and have incinerated about 650,000 metric tons of hazardous wastes to date. No casualties such as collisions, groundings, rammings, or fires have occurred, nor have there been any spills from loading incinerator ships in port. Although incinerator ship operations have established a good safety record, the number of voyages completed is too small to be used in estimating spill rates. Thus, we rely on accident data for tankers to estimate spills for the Vulcanus.

ESTIMATION OF RELEASING VESSEL CASUALTY (SPILL) RATES

ECO selected from its database accidents and spill events for tank ships of a size similar to the Vulcanus -- from 2,000 to 10,000 deadweight long tons. These data were used to estimate releasing vessel casualty or "spill" rates for four types of accidents and for areas corresponding to the locations of interest for the proposed operation of the Vulcanus. These spill rates were then adjusted for the design, location, and operating features for the Vulcanus that are expected to reduce the frequency of spills below that experienced worldwide by tank ships of similar size.

The design features adjusted for include the double hull, double bottom construction of the Vulcanus and the ship's controllable pitch (CP) propeller with bow thruster. The double hull, double bottom construction is expected to reduce the probability that cargo is released in the event of an accident, and the CP propeller with bow thruster is expected to reduce the probability of impact-type accidents, especially at low speeds, by improving the maneuverability of the vessel. With regard to location, the generally soft-bottom conditions in the Gulf are expected to reduce the rate of spills due to groundings below the rate experienced worldwide. Finally, operating restrictions that the Coast Guard plans to impose also are expected to reduce spill rates.

As an example of the operating restrictions noted above, the Coast Guard will require all movements of the Vulcanus in the Port of Mobile, both inbound and outbound, to be under the direction of the Captain of the Port, and a 24 hour advance notice will be required prior to the ship entering Mobile Bay.1/ This notice will include a report on the condition of the vessel's propulsion, steering, navigation and cargo systems. The Coast Guard will allow the Vulcanus to transit the harbor only during daylight hours, with a minimum of two miles visibility. In addition, the Captain of the Port will issue a local Notice To Mariners establishing a moving safety zone of 300 feet in all directions around the ship. Vessels will be prohibited from entering this zone without specific approval. The effect of the safety zone is to prohibit oncoming vessels from the Mobile Harbor ship channel while the Vulcanus is in the harbor, and to keep vessels traveling in the same direction as the Vulcanus at least 300 feet away. The Coast Guard will escort the Vulcanus to enforce the safety zone. The Coast Guard also will require the ship to be escorted by two tugs while it is in the harbor. While the ship is in transit in the Gulf or in the Gulf burn zone, the USCG will broadcast a Notice To Mariners notifying them of the ship's position and advising them to steer clear of the vessel.2/

1/The discussion of USCG provisions governing the Vulcanus is based on the statement of Rear Admiral Clyde T. Lusk, Jr., Chief, Office of Merchant Marine Safety, United States Coast Guard, before the House Subcommittee on Fisheries and Wildlife Conservation and the Environment, Subcommittee on Oceanography, December 7, 1983.

2/In addition to these operating precautions, USCG inspection requirements for incineration vessels include annual inspection of navigational and fire-fighting equipment, biennial inspection of the exterior of the hull and interior of the cargo tanks, and ultrasonic testing of hull thickness every five years. These steps should ensure the maintenance of the ship's navigational and structural integrity as long as it is permitted to incinerate hazardous wastes, and reduce the probability of non-impact related casualties.

The precise effect that these factors may have in reducing the rate of spills is difficult to determine. The adjustments made are based on published studies, observed differences in spill rates, kinetic energy levels likely for accidents in different locations, and professional judgment. No downward adjustments were made to the spill rate for non-impact type accidents because of insufficient information. The calculations of spill rates and the adjustments made to them are fully discussed in Appendix C.

The results of ECO's calculations are summarized in Exhibit 5-1. These data give spill rates (any size spill) for each location and type of casualty on a per voyage basis. The overall spill rate is quite low -- about 6 per 100,000 voyages. The data in Exhibit 5-2 show the relative frequency of spills by location and type of casualty, i.e., which locations and types of casualties have greater or lesser probability of occurence. These data indicate that the pier and coastal areas have the highest expected spill rates -- about 70 percent of spills would be expected to occur in those areas.[3]

WASTE QUANTITIES RELEASED

ECO also estimated the probability that accidents resulting in a spill involve one, two, and three or more tanks. Their estimates for impact type casualties (collisions, groundings, or rammings) are as follows:

- one tank - 80 percent
- two tanks - 15 percent
- three or more tanks - 5 percent

There is little information on which to base such estimates for non-impact type casualties. Accordingly, the same distribution is assumed, but there obviously is some amount of uncertainty regarding this assumption.

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[3] Most of the risk of spill in the "pier and harbor" area is from non-impact type accidents during loading at the pier. These rates were not adjusted downward, as explained in the text, so they are conservative upper-bound estimates.

The data in Exhibit 5-1, along with the data above on the percentage of spills involving one, two, or more tanks, may be used to calculate the spill rates by location and number of tanks involved. Exhibit 5-3 expresses these spill rates on a per voyage basis, while Exhibit 5-4 gives estimated spill rates (for the PCB case) in terms of operating years. These data indicate that spills in any location are very unlikely. The overall average spill rate is 6 per 100,000 voyages, or about 1 spill per 1,200 operating years. The rate of spill events where two or three or more tanks are involved is even lower -- 9 and 3 spills per million voyages, respectively. These rates equal an average of one two-tank spill per 8,000 operating years, and one spill of three or more tanks per 24,000 operating years. Spill rates for particular locations are, of course, less than the overall spill rate. For example, the spill rates for Mobile Bay when one, two, or three or more tanks are involved are 1 per 13,000, 67,000, and 200,000 operating years, respectively, with an overall spill rate of 1 per 10,000 operating years.

The amount of cargo likely to be released from a tank affected by an accident depends on many factors, such as the nature of the accident (the location and extent of damage to the tank), the specific gravity of the waste, sea conditions, and the length of time before some action is taken to lessen cargo outflow. For example, in many collisions the impact is severe enough to put the cargo in free communication with the sea. In such accidents virtually the entire cargo of a tank could be lost in a relatively short period of time. Groundings, on the other hand, usually crack or puncture the hull far below the water line. The pressure from cargo in the tank that resides above the water line usually will force a portion of the cargo out of the tank. The amount of additional cargo loss and the time over which it will occur depends on the extent of the damage and the density of the waste relative to sea water. Wastes with densities greater than sea water will tend to flow out as sea water flows in and floats to the top of the tank. Outflow of waste of lesser density probably would not be as extensive. Finally, rammings tend to create punctures at or near the water line. Cargo above the water line would be lost rather quickly. Cargo below the water line could also be lost if the density of the waste were less than sea water and the sea water was able to circulate into the tank, allowing the lighter waste to float out.

We have not developed spill size distributions or expected spill sizes for accidents involving various numbers of tanks, since data are not available to make such estimates. Rather, we have made the conservative assumption that the entire contents of tanks affected by accidents are released.

The "expected" amount of waste released on an annual basis is calculated for PCB and EDC wastes in Exhibit 5-5. We emphasize that the expected values represent an annual average used only as an index to compare releases from the various components of incineration systems and do not suggest that spills would occur each year. Expected annual releases are estimated to be about 0.63 MT for PCB wastes and 0.77 MT for EDC wastes. These calculations are conservative, in that we assume that any tank involved in a spill releases its entire contents, and that the entire ship's cargo is released in accidents involving three or more tanks. The expected values reflect the large quantity of waste that could be released in a spill and the extremely low probability that a spill would occur. As noted above, the estimated spill rate for the Vulcanus is 6 per 100,000 voyages, or (in the PCB case) 1 per 1,200 operating years. Given these estimates, it is unlikely that a spill will occur within the ship's operating life.

CAVEATS AND SENSITIVITY ANALYSIS

Vessel Casualty Rates

The vessel casualty rates employed to analyze potential releases from the Vulcanus are based on historic ship casualty data, with consideration of the specific conditions under which the Vulcanus would operate. The casualty estimates account for such factors as U.S. Coast Guard (USCG) requirements, the double-hulled, double-bottomed design, the use of a CP propeller with bow thruster, the bottom conditions in the Gulf, and the size of the vessel. As a result, the estimated spill rates for the Vulcanus are lower than for a typical tanker.

For purposes of comparison, Exhibit 5-6 shows the spill rate estimated for the Vulcanus as a percent of the historical spill rates for typical tank ships operating in similar areas as the Vulcanus. The data indicate that the likely spill rate for the Vulcanus is substantially less than that experienced by tankers world wide. This is especially the case for impact type accidents in the bay and pier/harbor areas. No adjustments were made for non-impact type casualties, so the data reflect only the fact that small size vessels have lower non-impact casualty rates than the average for the world fleet of tank ships. Overall, the Vulcanus is expected to have a spill rate of about 10 percent of that for typical tank ships.

Fugitive Emissions from the Vulcanus

While our analysis of marine transportation releases focuses on vessel casualties, we also considered potential fugitive emissions from the Vulcanus while the ship is underway. According to an ADL analysis, the ship may release fugitive emissions if an accidental discharge of waste liquid into the pumproom bilge occurs and a portion of the release volatilizes, or if a build-up of pressure in the cargo tanks necessitates use of pressure relief valves. Fugitive emissions of this type are difficult to estimate accurately. A rough estimate made by ADL suggests that these sources are likely to release less than about 4 kilograms of fugitive emissions per voyage. Annual fugitive emissions would be about 50 kilograms and 70 kilograms of waste in the PCB and EDC cases, respectively. Since these emissions are small, would consist mainly of the more volatile portions of the waste, and would be released and dispersed, on average, all along the ship's path of transit, their environmental and human health effects would be neglibible.4/ Further, any material that did not volatilize when accidentally discharged to the bilge would be retained in tanks on board and eventually would be pumped to an onshore facility for storage or subsequent incineration.

Remedial Action

The preceding analysis does not consider remedial action to remove waste materials released to the environment as a result of spills, as this was beyond the scope of this study. Hazardous waste operators are required to develop a contingency plan for handling spills as a condition of the permit. The effectiveness of remedial actions would depend on many factors, such as the location and type of accident, sea conditions, weather conditions, currents, properties of the material, and response time. We think that efforts to contain and recover spills are

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4/IEc copy of memorandum from J. Hagopian (ADL) to J. Ehrenfeld (ADL), "Fugitive Emissions from Incinerator Ships," 19 September 1984.

most likely to be successful in enclosed areas or in shallow waters, such as the pier and harbor area and Mobile Bay. To the extent that such mitigating activities are effective, the amount of waste remaining in the marine environment after a spill will be less than the releases we estimate.

COMPARABLE HAZARDS

To characterize the relative effect that operation of the Vulcanus would have on expected releases of hazardous substances in the Gulf of Mexico or Mobile Harbor, we examined data on the shipments of petroleum and hazardous materials in Mobile Harbor and the Gulf. These data show that there is a substantial volume of shipments of petroleum and hazardous substances in both Mobile Harbor and the Gulf of Mexico.

The table below provides data on the average volume of crude petroleum, petroleum derivatives, and chemicals shipped in and out of Mobile Bay over the period 1977 to 1981.[5]

Table 5-1

AVERAGE ANNUAL PETROLEUM AND CHEMICAL SHIPMENTS IN MOBILE BAY

Commodity	Imports, Exports & Coastwise (Tankers)	Internal & Local (Barges)
	(000 MT)	(000 MT)
Crude Petroleum	1,445	2,203
Gasoline, Jet Fuel, Kerosene, Fuel Oil & Solvents	386	3,632
Benzene, Toluene, & Basic Chemicals	42	113
Total	1,873	5,948

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[5] Derived from Waterborne Commerce of the United States, Part 2, Waterways and Harbors -- Gulf Coast, Mississippi River System and Antilles, Calendar Years 1977-1981, Department of the Army, Corps of Engineers.

The expected volume of wastes to be carried by the Vulcanus (56,000 to 68,400 MT) is less than 4 percent of the volumes of the above commodities carried by tankers and is less than 1 percent of the volumes carried by both tankers and barges. Since the relative frequency of spills from the Vulcanus is less than from tank ships generally (and assuming spill rates for barges are similar), the expected volume of releases from the Vulcanus in the pier and harbor areas and Mobile Bay, in a statistical sense, is only about 0.1 percent of expected releases from ongoing shipments of these commodities.

Data on shipments of petroleum and hazardous substances in the Gulf area in FY 1983 are shown in the table below.[6]

Table 5-2

SHIPMENTS OF PETROLEUM AND HAZARDOUS SUBSTANCES IN THE GULF OF MEXICO, FY 1983

	Petroleum	Hazardous Substances
Volume of shipments (MM MT)	270	274
Number of shipments		
Tankers	8,290	1,947
Barges	36,627	13,031

The number of voyages by the Vulcanus per year would be about 0.2 percent of total tanker shipments (about 0.03 percent of tanker and barge shipments) and the volume of waste carried by the Vulcanus would be about 0.01 percent of the volume of petroleum and hazardous substances shipped by both tankers and barges in the Gulf area. Given the lower expected spill rate for the Vulcanus, the expected volume of releases from the Vulcanus is less than 0.002 percent of expected releases from ongoing shipments of petroleum and hazardous substances in the Gulf area.

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[6] Information from U.S. Coast Guard, Port and Environmental Safety Division.

SUMMARY OF RELEASES FROM OCEAN TRANSPORTATION

Our analysis indicates that the overall spill rate for the Vulcanus (all locations combined) is very low -- 6 per 100,000 voyages or, in the PCB case, about 1 per 1,200 operating years. Spill rates estimated for particular locations are even lower, as are spill rates for accidents involving two or three or more tanks. For example, the overall spill rate for Mobile Bay is about 1 per 10,000 operating years, with the spill rate for accidents involving one, two, or three or more tanks being about 1 per 13,000, 67,000, and 200,000 operating years, respectively. The overall spill rate for the coastal area is about 1 per 4,000 operating years, with the spill rate for accidents involving one, two, or three or more tanks being about 1 per 5,000, 25,000, and 75,000 operating years, respectively.

The overall spill rate estimated for the Vulcanus is about one order of magnitude less than the historical spill rate for tank ships worldwide. This is due to the adjustments made to historical spill rates to reflect the likely effects of the design and operating characteristics of the Vulcanus. However, no downward adjustments, other than for the size of the vessel, were made to spill rates from non-impact casualties, because of insufficient information.

The amount of expected annual releases of PCB and EDC wastes are also low, about 0.63 MT and 0.77 MT, respectively. These numbers represent long-term averages, rather than the releases likely to occur in any year. They are also conservative estimates, as we assumed complete loss of the cargo of tanks affected by an accident.

The Vulcanus would operate in a region of the country having substantial commerce in petroleum and hazardous materials. The volume of material transported by the Vulcanus would be a small fraction of shipments of such commodities in the Gulf -- about 0.01 percent. Further, because the spill rate for the Vulcanus is less than for other vessels, the potential releases from the Vulcanus would be less than 0.002 percent of those from ongoing shipments of petroleum and hazardous materials in the Gulf.

Exhibit 5-1

ESTIMATED SPILL RATES PER VOYAGE FOR THE VULCANUS BY TYPE OF CASUALTY AND LOCATION

Location	Type of Casualty				
	Collisions	Groundings	Rammings	Non-impact	All Casualties
Pier & Harbor	4.3E-6	2.2E-7	1.6E-7	1.8E-5	2.3E-5
Mobile Bay	1.9E-6	3.4E-6	1.4E-6	3.6E-7	7.1E-6
Coastal	6.4E-6	6.7E-6	2.4E-6	3.6E-6	1.9E-5
Burn Zone	4.5E-6	-	-	7.1E-6	1.2E-5
All Locations	1.7E-5	1.0E-5	4.0E-6	2.9E-5	6.0E-5

Source: Appendix C, Table 7

Exhibit 5-2

DISTRIBUTION OF EXPECTED SPILLS BY TYPE OF CASUALTY AND LOCATION

Location	Collisions	Groundings	Rammings	Non-impact	All Casualties
	Type of Casualty				
Pier & Harbor	0.071	0.004	0.003	0.297	0.375
Mobile Bay	0.032	0.056	0.024	0.006	0.118
Coastal	0.106	0.111	0.040	0.059	0.315
Burn Zone	0.074	-	-	0.118	0.192
All Locations	0.284	0.171	0.066	0.479	1.000

Note: This table indicates the relative frequency of spills by casualty and location. The data are calculated from Exhibit 5-1 by dividing the estimated spill rate for a given casualty type and location by the overall spill rate. For example, relative fequency for collisions in pier and harbor area of 0.071 is calculated by dividing the spill rate of 4.3E-6 by the overall spill rate of 6.0E-5.

Source: Exhibit 5-1

Exhibit 5-3

ESTIMATED SPILL RATES PER VOYAGE FOR THE VULCANUS BY LOCATION AND NUMBER OF TANKS AFFECTED

Location	Number of Tanks Affected			
	One	Two	Three or More	Any Number
Pier & harbor	1.8E-5	3.4E-6	1.1E-6	2.3E-5
Mobile Bay	5.7E-6	1.1E-6	3.6E-7	7.1E-6
Coastal	1.5E-5	2.9E-6	9.5E-7	1.9E-5
Burn Zone	9.3E-6	1.7E-6	5.8E-7	1.2E-5
Total	4.8E-5	9.0E-6	3.0E-6	6.0E-5

Source: Appendix C, Table 7 and IEc Analysis

Exhibit 5-4

SPILL RATES IN TERMS OF NUMBER OF OPERATING YEARS *

Location	Number of Tanks Affected			
	One	Two	Three or More	Any Number
Pier & harbor	4,000	21,000	63,000	3,000
Mobile Bay	13,000	67,000	200,000	10,000
Coastal	5,000	25,000	75,000	4,000
Burn Zone	8,000	41,000	120,000	6,000
Total	1,500	8,000	24,000	1,200

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* The spill rate is one per the number of operating years shown above and is calculated assuming 14 voyages per operating year.

Source: Derived from Appendix C, Table 7

Exhibit 5-5

CALCULATION OF EXPECTED ANNUAL RELEASES (EV) FROM VESSEL CASUALTIES

PCB CASE

Expected release fraction (ERF) = 0.1875

Quantity at risk (Q) = 4,000 MT

Average quantity released (QR) = ERF * Q = 750 MT

Expected number of releases per year (EN) = 8.4E-4

Expected annual release (EV) = QR * EN = 0.63 MT

EDC CASE

Expected release fraction (ERF) = 0.1875

Quantity at risk (Q) = 3,800 MT

Average quantity released (QR) = ERF * Q = 712 MT

Expected number of releases per year (EN) = 1.1E-3

Expected annual release (EV) = QR * EN = 0.77 MT

Source: Appendix C, IEc Analysis

Exhibit 5-6

ESTIMATED SPILL RATE OF THE VULCANUS AS A PERCENT OF THE HISTORICAL SPILL RATES FOR TANK SHIPS BY TYPE OF CASUALTY AND LOCATION *

Location	Type of Casualty		
	Impact	Non-Impact **	All Casualties
Pier and Harbor	3.6%	75.5%	14.6%
Mobile Bay	4.5	13.7	4.7
Coastal	10.3	13.5	10.8
Burn Zone	68.8	5.8	8.9
All Locations	7.2	16.3	9.8

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* We compute these percentages by comparing the estimated spill rates for the Vulcanus to the spill rates obtained from ECOTANK for tank ships between 2,000 and 10,000 deadweight tons. ECOTANK has five location categories: pier; harbor; entranceway to a harbor; coastal (within 50 nautical miles of land); and at sea. For purposes of this analysis we compare ECOTANK pier and harbor data to the estimated spill rates for the Vulcanus in Mobile pier and harbor, ECOTANK entranceway data to our estimated spill rates for Mobile Bay, ECOTANK coastal data to our estimated spill rates for coastal waters, and ECOTANK at sea data to estimated spill rates for the Vulcanus in the burn zone.

** The only adjustment affecting the spill rate of the Vulcanus from non-impact casualties is for vessel size.

Source: Derived from Tables 7 and 8, Appendix C

RELEASES FROM INCINERATION

CHAPTER 6

INTRODUCTION

Unlike some releases from other components of ocean- or land-based incineration systems, stack emissions are expected as part of normal operations. This chapter presents our analysis of expected stack emissions, addressing four classes of pollutants:

- Undestroyed constituents of the waste stream;
- Products of Incomplete Combustion (PICs);
- Heavy metals; and
- Hydrochloric acid (HCl).

We use existing or proposed EPA permit requirements and available test burn data to estimate annual releases of each of these materials.

In addition to stack emissions, the analysis of releases from land-based incinerators includes estimates of the quantity and content of scrubber effluent generated annually. Land-based incinerators typically are equipped with scrubbers to control emissions of HCl, metals, and particulates. The analysis of incineration aboard the Vulcanus does not consider releases of scrubber water because the Vulcanus has no scrubber.

The analysis ignores releases of ash from both the Vulcanus and land-based incinerators. CWM does not expect the Vulcanus' liquid injection incinerators to generate ash residues. If any ash is generated, EPA's draft permit for the Vulcanus prohibits the ship from dumping it at sea and requires CWM to dispose the ash on land in accordance with applicable EPA regulations. Similarly, we assume that any ash generated by a land-based incinerator would be properly disposed in an EPA-permitted hazardous waste landfill.

EMISSIONS OF UNDESTROYED WASTES

Exhibit 6-1 illustrates our calculation of emission rates for undestroyed wastes for both the PCB and EDC wastes. The calculation assumes that the Vulcanus meets EPA's proposed performance standards for ocean-based incineration, and that the land-based incinerator meets existing EPA standards for hazardous waste incinerators. The two standards are identical, requiring both ocean- and land-based incinerators to achieve a destruction and removal efficiency (DRE) of 99.99 percent.1/ The only exception to this requirement is for incinerators burning PCBs, dioxins, and dibenzofurans, which EPA requires to achieve a DRE of 99.9999 percent. Based on these requirements and the total annual throughput for the PCB and EDC wastes, we calculated the following emissions of undestroyed wastes for the Vulcanus and the land-based incinerator:

- Emissions for incineration of the PCB waste - .056 metric tons per year;
- Emissions for incineration of the EDC waste - 6.84 metric tons per year.

Annual emissions of undestroyed wastes are significantly higher in the EDC case since the DRE required for EDC wastes is two orders of magnitude lower than that for PCB wastes.

As described previously, we assume that the PCB waste contains 35 percent by weight of PCBs and EDC waste contains 50

1/The standard for ocean incineration is in terms of destruction efficiency, rather than destruction and removal efficiency, because scrubbers are not used. We use the term DRE for both systems to simplify the discussion.

percent by weight of ethylene dichloride. The remainder of each waste stream is assumed to be non-hazardous. Thus, each of these wastes contains a single "primary organic hazardous constituent" (POHC) as defined in EPA's current regulations for land-based incinerators. In the calculations above, we assume both the POHC and the non-hazardous constituents are destroyed equally. As shown on Exhibit 6-1, the resulting annual release of POHCs only is 0.02 metric tons for the PCB waste and 3.42 metric tons for the EDC waste. These POHC releases are used in our analysis of human health and environmental effects from stack releases presented in Chapters 7 and 8.

PIC EMISSION RATES

The formation of products of incomplete combustion (PICs) by hazardous waste incinerators is a poorly understood phenomenon, and the topic of considerable debate. By strict definition, PICs are organic compounds formed by chemical reactions during the incineration process. Trial burn data, however, may identify as PICs all organic compounds other than POHCs present in the stack gases. These compounds may include not only those formed during combustion, but also compounds from contaminated scrubber water or non-combusted trace components of the waste feed itself. We developed our estimates of PIC emissions based on the best available trial burn data for ocean- and land-based facilities. These data, however, are too limited to present a definitive portrayal of PIC emissions. Specifically, the data are plagued by the following uncertainties:

- The PIC emission data are based on differing definitions of what constitutes a PIC. In some trial burns PICs are defined as compounds not found in the waste itself, while in others PICs are compounds not detected in the waste in concentrations greater than 100 ppm.
- The trial burn data are not based on consistent sampling procedures. Further, the trial burns did not sample for a consistent set of compounds, so the results depend upon whether investigators tested for the presence of a particular compound.

- The trial burn data are not based on burns of a consistent set of wastes, and none of the wastes analyzed are identical to the PCB or EDC wastes of concern in this study.

- The emission rates measured in trial burns are based on several types of incinerators with different operating parameters. PIC generation is believed to be a function of incinerator type, configuration, and operating conditions.

- Finally, there is disagreement over the validity of the results of some test burns due to possible contamination of samples.

With these uncertainties in mind, our estimates of PIC emission rates should be viewed only as rough approximations. However, in the absence of better data or an improved theoretical understanding of PIC generation, we believe these estimates are the best available.2/

PIC Emissions from the Vulcanus

We base our estimates of PIC emission rates for the Vulcanus II on available trial burn data for the ship and for its sister ship, the Vulcanus I. As explained in Appendix E, these data yield the following estimates:

- For PCB wastes burned at 99.9999 percent DRE, hazardous PICs are emitted at a rate no greater than 1.13E-11 percent of total waste feed;

- For non-PCB wastes burned at 99.99 percent DRE, PICs are emitted at a rate of 3.01E-2 percent of total waste feed.

As these estimates show, ocean-based incineration is assumed to generate significantly less PICs when burning the PCB waste than when burning EDC waste. This large difference is partly the result of two factors:

2/Appendix E reviews the test burn data and fully explains the methodology employed to derive the PIC emission estimates.

- Past trial burns of PCB-containing wastes on the Vulcanus I and II tested for a single compound only, while burns of other organic wastes were tested for many compounds, and [3]

- Some experts believe that the higher DRE required for PCB wastes should result in lower generation of PICs.

However, the large discrepancy between the two wastes raises concern for the accuracy of the estimates. As shown below and in Appendix E, additional cause for concern is a further discrepancy in relative PIC generation rates for land- and ocean-based incinerators. The test burn data for PCB wastes indicate that land-based incinerators generate more PICs than ocean-based incinerators, but the data for non-PCB wastes show that land-based incinerators generate considerably fewer PICs. At present, we know of no complete explanation for these apparent inconsistencies.

We used these PIC emission rates and the throughput data described above to calculate total annual releases of PICs for both the PCB and EDC wastes. These calculations, summarized in Exhibit 6-2, produce the following estimates:

- PIC emissions from PCB burns: 6.3E-9 metric tons per year;

- PIC emissions from EDC burns: 20.6 metric tons per year.

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[3] As described in Appendix E, ten PCB burns onboard the Vulcanus revealed no detectable levels of tetrachlorodibenzo-p-dioxin (TCDD), the PIC of interest in this analysis. The estimated PIC emission rate given above is based on the maximum quantity of TCDD that could have gone undetected. The trial burns did not analyze other PICs.

In light of the anomalies in the test burn data, and given the highly carcinogenic nature of PICs that may be generated by PCB incinerators, we include in Chapter 8 a sensitivity analysis for at-sea incineration of PCB wastes which employs the higher PIC generation rate given for land-based incinerators. As shown in Exhibit 6-2, use of this higher rate increases the annual quantity of PIC emissions in the PCB case by more than three orders of magnitude (to 1.9E-5 metric tons per year) for the ocean case.

PIC Emission Rates for Land-Based Incinerators

Like the estimates of PIC emissions from the Vulcanus, our estimates of PIC emissions from land-based incineration are based on the analysis of test burn data described in Appendix E, and are subject to the same uncertainties. With these caveats in mind, we calculated the following PIC emission rates for land-based incineration:

- For PCB wastes burned at 99.9999 percent DRE, hazardous PICs are emitted at a rate of 3.40E-8 percent of total waste feed; [4]

- For non-PCB wastes burned at 99.99 percent DRE, PICs are emitted at a rate of 8.94E-4 percent of total waste feed.

Based on these emission rates, we calculated the following estimates of total annual PIC emissions for the PCB and EDC cases:

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[4] The PIC emission rate reported above is for TCDD only. As described in Appendix E, the test burn data indicate that furans and other dioxins also are generated as PICs at land-based incinerators burning PCB wastes. We based our estimate of PIC emission rates solely on TCDD emissions because EPA recommends that risk analyses for emissions containing mixtures of furans and dioxins be based on TCDD emissions and the unit risk factor for TCDD. Since the PIC emission rate for PCB burns aboard the Vulcanus also reflects only TCDD emissions, the estimates for the two systems are directly comparable.

- PIC emissions from PCB burns: 1.9E-5 metric tons; and
- PIC emissions from EDC burns: 0.61 metric tons.

Exhibit 6-3 contains the calculations employed to develop these estimates.

METALS EMISSIONS

Ocean-Based Incineration

Because the Vulcanus is not equipped with scrubbers, its stack emissions include any metals contained in the waste feed. To control metals emissions, EPA plans to issue metals concentration limits for wastes burned at sea. Current proposals include individual limits on a number of metals, with a maximum limit for total metals on each manifested shipment of wastes of 500 ppm. For purposes of analysis, we assumed that both the PCB and EDC wastes contain arsenic, cadmium, chromium, and nickel -- the four metals for which EPA's Carcinogen Assessment Group (CAG) has developed cancer unit risk factors -- at concentrations of 100 ppm each.[5] The concentration assumptions probably overstate the average concentrations of carcinogenic metals in liquid incinerable waste streams.

Based on this assumption, Exhibit 6-4 shows expected annual metals emissions for the Vulcanus. As the exhibit indicates, estimated metals emissions in the PCB case are 5.6 metric tons per year for each metal, or a total of 22.4 metric tons. Estimated annual emissions in the EDC case are 6.84 metric tons of each metal, for a total of 27.36 metric tons per year.

Land-Based Incineration

Our analysis of metals emissions from land-based incinerators assumes the same concentration of metals in the waste feed as the ocean-based analysis, but considers the effect of a scrubber in removing metals. As explained in Appendix D, there is significant uncertainty associated with scrubber removal efficiencies. Based on available trial burn data and discussions with EPA experts, we assumed that scrubbers achieve 90 percent removal of cadmium, chromium and nickel, and 50 percent removal of arsenic. Removal of arsenic is lower because this metal is more volatile. These assumptions yield the following estimates of annual metals emissions for a land-based incinerator:

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[5] Appendix D gives a fuller explanation of the rationale employed in selecting these metals.

- PCB Case: 0.56 metric tons each of cadmium, chromium and nickel, and 2.8 metric tons of arsenic;
- EDC Case: 0.684 metric tons each of cadmium, chromium and nickel, and 3.42 metric tons of arsenic.

In the PCB case, metals emissions total 4.48 metric tons per year. In the EDC case, annual metals emissions total 5.47 metric tons. Exhibit 6-5 summarizes the calculations used to develop these estimates.

HYDROCHLORIC ACID EMISSIONS

Ocean-Based Incineration

The lack of scrubbers on the Vulcanus implies that chlorine contained in the waste feed will be emitted from the incinerator stacks. Most chlorine is emitted as hydrochloric acid (HCl), while the rest may be emitted as chloride salts or chlorinated organic matter. We did not analyze the forms in which chlorine may be emitted, but simply calculated the total quantity of chlorine released and assumed that it would be released as HCl. Based on a mass balance calculation, we estimated that in the PCB case, 10,505 metric tons of chlorine per year are released. In the EDC case, 25,034 metric tons of chlorine per year are released. We base these estimates on the assumption that Arochlor 1254 (53.6 percent chlorine) or EDC (73.2 percent chlorine) is the only source of chlorine in the PCB or EDC waste (that is, we assume that the balance of the waste is composed of non-chlorinated organics).

Land-Based Incineration

The presence of scrubbers on land-based incinerators greatly reduces emissions of HCl and other chlorinated compounds. According to an ADL analysis (see Appendix F), scrubbers achieve 99 percent removal of hydrochloric acid emissions. Based on this removal efficiency, ADL estimated annual emissions of 105 and 250 metric tons of chlorine, in the form of HCl, for the PCB and EDC cases, respectively.

SCRUBBER EFFLUENT

Appendix F describes ADL's analysis of the generation, composition, and disposition of scrubber effluent from land-based incinerators. The analysis assumes the scrubber achieves 99 percent removal of hydrochloric acid emissions, as EPA requires. Based on these and other assumptions explained in Appendix F, ADL estimated that an incinerator burning 56,000 metric tons of PCB wastes annually generates approximately 1.5 million metric tons of scrubber blowdown. A unit incinerating 68,400 metric tons of EDC wastes annually produces approximately 3.6 million metric tons of scrubber blowdown. Waste water accounts for more than 99 percent of both these quantities.

As discussed in Appendix F, chlorine is the principal non-aqueous constituent of scrubber blowdown, representing 0.7 percent of the total effluent. In the PCB case, ADL estimated that 10,400 metric tons of chlorine per year are contained in scrubber effluent. In the EDC case, ADL estimated that 24,784 metric tons of chlorine are removed by scrubbers and contained in scrubber blowdown.

EPA regulates disposal of scrubber sludge or brine under RCRA and controls the discharge of scrubber waste water under the Clean Water Act, limiting the probability that hazardous scrubber wastes will be released to the environment. In fact, three of four incinerator operators contacted by ADL sell scrubber effluent to be used, reused, recovered or recycled, eliminating the release of any wastes to the environment. If scrubber waste water is discharged, the operators typically neutralize it, raising the pH to 7.0 or 7.5. As indicated above, its chlorine content is normally maintained below one percent, with most chlorine contained in low concentrations of dissolved salts. At a pH of 7.0 or above there is virtually no hydrochloric acid in the effluent. Scrubber effluent also contains virtually no organic material.

Treated scrubber effluent also can contain metals removed from stack emissions. Assuming the scrubber removal efficiencies described above, the maximum quantity of metals contained in waste scrubber water will equal 40 percent of the total throughput of cadmium, chromium, and nickel, and one-half the total throughput of arsenic. Therefore, the maximum quantity of metals contained in scrubber effluent from PCB incineration would be 17.92 metric tons per year (5.04 metric tons each of cadmium, chromium, and nickel, and 2.8 metric tons of arsenic); and 21.89 metric tons per year (6.156 metric tons of cadmium, chromium, and nickel, and 3.42 metric tons of arsenic) in the EDC case. Exhibit 6-6 illustrates the calculation of these estimates.

CAVEATS AND SENSITIVITY ANALYSIS

In addition to the caveats regarding estimates of PIC emissions, this analysis assumes incinerators operate to meet EPA permit conditions. With regard to this assumption, there has been concern that periodic incinerator malfunctions or "upsets" could lead to significant releases of unburned wastes. Federal regulations require incinerators to be equipped with automatic waste feed cutoff systems that prevent operation of the incinerator in the event that critical operating conditions are not met. In addition, the thermal inertia of a hazardous waste incinerator is such that any wastes introduced into the system immediately before and during an upset would be substantially combusted. If automatic waste feed cutoff normally occurs in less than one second and destruction efficiency in the event of an upset is at least 99.9 percent, incinerator malfunctions should have an insignificant effect on annual stack emissions. In our worst case analysis--shutdown of operations within ten seconds, maintaining only 90 percent DRE--emissions during the upset period would be equivalent to normal emissions over three hours of operation at 99.99 percent DRE, or 280 hours of operation at the more stringent PCB level of 99.9999 percent DRE.6/ In this case, about ten such upsets over the burn period

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6/Memorandum from J.R. Ehrenfeld (ADL) to Incineration Risk Study File, "Potential Emissions Due to Incinerator Malfunction," 15 August 1984.

for PCBs of 296 hours would have the effect of reducing DRE by one order of magnitude. There would have to be about 600 such upsets over the 169 hour burn period to reduce the DRE for EDC by about an order of magnitude. Unfortunately, we have no data on the number of upsets likely to occur.

SUMMARY

Ocean-Based Incineration

Our estimates of annual stack emissions from an ocean-based incineration system are:

Table 6-1

Summary of Ocean-Based Stack Emissions

	PCB Waste (MT per year)	EDC Waste (MT per year)
Undestroyed Wastes	5.60E-2	6.84E+0
PICs	6.33E-9	2.06E+1
Metals	2.24E+1	2.74E+1
Chlorine (as HCl)	1.05E+4	2.50E+4

Source: IEc Analysis

The quantity of chlorine emitted as HCl clearly dominates releases of the three other categories of emissions. Undestroyed wastes, PICs, and metals emissions, however, are of greater concern in characterizing the magnitude of potentially hazardous emissions. As the table shows, our assumptions result in a substantial quantity of metals emitted from the Vulcanus in both the PCB and EDC cases. PIC emissions are also large in the EDC case, but represent a far smaller share of total emissions in the PCB case. Emissions are higher in the EDC case because the waste is burned at a lower DRE, the PIC generation rate is substantially higher, and the waste contains more chlorine than the PCB waste.

Land-Based Incineration

Our estimates of likely annual stack emissions from a land-based hazardous waste incinerator are:

Table 6-2

Summary of Land-Based Stack Emissions

	PCB Waste (MT per year)	EDC Waste (MT per year)
Undestroyed Wastes	5.60E-2	6.84E+0
PICs	1.90E-5	6.11E-1
Metals	4.48E+0	5.47E+0
Chlorine (as HCl)	1.05E+2	2.50E+2

Source: IEc Analysis

The stack emissions for both wastes contain more chlorine (as HCl) than any other category of emissions. The quantity of HCl released, however, is likely to be of less concern than the quantity of undestroyed wastes, metals and PICs. The table shows that a substantial quantity of metals is released in both the PCB and EDC cases, with metals emissions exceeding emissions of both PICs and undestroyed wastes in the PCB case. The table also shows that emissions of undestroyed wastes exceed PIC emissions by two orders of magnitude in the PCB case, and one order of magnitude in the EDC case. Total annual PIC emissions in the EDC case are approximately three orders of magnitude higher than the PCB case.

Releases from land-based incinerators can also include scrubber wastes containing substantial quantities of chlorine and metals. Because the disposal of scrubber sludge, brine and waste water are regulated by EPA, uncontrolled releases of these materials in hazardous form are unlikely. The presence of scrubbers reduces stack emissions of chlorine as HCl two orders of magnitude below similar emissions for the Vulcanus.

Similarly, scrubbers reduce expected annual metals emissions from a land-based unit to 20 percent of the expected metals emissions from the sea-based system.

As noted above, emissions of undestroyed wastes from land-based incinerators are assumed to be the same as from the Vulcanus. PIC emissions, however, differ markedly. In the EDC case, annual PIC emissions are two orders of magnitude lower for land-based incinerators. In the PCB case, the opposite appears to hold; PIC emissions for land-based incinerators are estimated to be three orders of magnitude higher than PIC emissions for the Vulcanus. As described previously, this apparent anomaly and the uncertainties associated with the PIC analysis raise considerable questions regarding the accuracy of the PIC estimates for both the land-based and ocean-based systems.

Exhibit 6-1

CALCULATION OF ANNUAL EMISSIONS OF UNDESTROYED WASTES

PCB Waste

Assumptions:

DRE = 99.9999%
Annual throughput = 56,000 MT

Calculation:

Annual emissions of undestroyed wastes = 56,000 MT * (1-.999999)
= .056 MT

Annual emissions of POHC (PCB) = .020 MT

EDC Waste

Assumptions:

DRE = 99.99%

Annual throughput = 68,400 MT

Calculation:

Annual emissions of undestroyed wastes = 68,400 MT * (1-.9999)
= 6.84 MT

Annual emmisions of POHC (EDC) = 3.42 MT

Source: IEc Analysis

Exhibit 6-2

CALCULATION OF ANNUAL PIC EMISSIONS FROM THE INCINERATOR SHIP

PCB Waste

Assumptions:

PIC emission rate = 1.13E-11% of waste feed
Annual throughput = 56,000 MT

Calculation:

Annual PIC emissions = 56,000 MT * 1.13E-13
= 6.33E-9 MT

EDC Waste

Assumptions:

PIC emission rate = 3.01E-2% of waste feed
Annual throughput = 68,400 MT

Calculation:

Annual PIC emissions = 68,400 MT * 3.01E-4
= 20.59 MT

PCB Sensitivity Analysis

Assumptions:

PIC emissions rate = 3.40E-8% of waste feed
Annual throughput = 56,000 MT

Calculation:

Annual PIC emissions = 56,000 MT * 3.40E-10
= 1.90E-5 MT

Source: IEc Analysis

Exhibit 6-3

CALCULATION OF ANNUAL PIC EMISSIONS FROM A LAND-BASED INCINERATOR

PCB Waste

Assumptions:

PIC emission rate = 3.40E-8 percent of waste feed
Annual throughput = 56,000 MT

Calculation:

Annual PIC emissions = 56,000 MT * 3.40E-10
= 1.90E-5 MT

EDC Waste

Assumptions:

PIC emission rate = 8.44E-4 percent of waste feed
Annual throughput = 68,400 MT

Calculation:

Annual PIC emissions = 68,400 MT * 8.94E-6
= 6.11E-1 MT

Source: IEc Analysis

Exhibit 6-4

ANNUAL METALS EMISSIONS FROM OCEAN-BASED INCINERATION

Metal	Concentration In Waste (ppm)	Annual Emissions	
		PCB Waste (MT)	EDC Waste (MT)
Arsenic	100	5.6	6.84
Cadmium	100	5.6	6.84
Chromium	100	5.6	6.84
Nickel	100	5.6	6.84
TOTAL		22.4	27.36

Source: IEc Analysis

Exhibit 6-5

CALCULATION OF ANNUAL METALS EMISSIONS FOR LAND-BASED INCINERATION

Assumptions

Metal	--Annual Throughput-- (MT) PCB Waste	EDC Waste	Scrubber Removal Efficiency
Arsenic	5.6	6.84	50 %
Cadmium	5.6	6.84	90 %
Chromium	5.6	6.84	90 %
Nickel	5.6	6.84	90 %
Total	22.4	27.36	

Calculations

Annual Emissions = Annual Throughput * (1 - Removal Efficiency)

PCB Waste - Cadmium, Chromium and Nickel:

Annual Emissions = 5.6 MT * (1 - .9)

= 0.56 MT

PCB Waste - Arsenic:

Annual Emissions = 5.6 MT * (1 - .5)

= 2.8 MT

EDC Waste - Cadmium, Chromium and Nickel:

Annual Emissions = 6.84 MT * (1 - .9)

= 0.684 MT

EDC Waste - Arsenic:

Annual Emissions = 6.84 MT * (1 - .5)

= 3.42 MT

Source: IEc Analysis

Exhibit 6-6

CALCULATION OF THE MAXIMUM QUANTITY OF METALS CONTAINED IN TREATED SCRUBBER EFFLUENT

Assumptions

Metal	--Annual Throughput-- (MT) PCB Waste	EDC Waste	Scrubber Removal Efficiency
Arsenic	5.6	6.84	50 %
Cadmium	5.6	6.84	90 %
Chromium	5.6	6.84	90 %
Nickel	5.6	6.84	90 %
Total	22.4	27.36	

Calculations

Quantity in Effluent = Annual Throughput * Removal Efficiency

PCB Waste - Cadmium, Chromium and Nickel:

Quantity in Effluent = 5.6 MT * .9
= 5.04 MT

PCB Waste - Arsenic:

Quantity in Effluent = 5.6 MT * .5
= 2.8 MT

EDC Waste - Cadmium, Chromium and Nickel:

Quantity in Effluent = 6.84 MT * .9
= 6.156 MT

EDC Waste - Arsenic:

Quantity in Effluent = 6.84 MT * .5
= 3.42 MT

Source: IEc Analysis

EFFECTS OF RELEASES FROM OCEAN TRANSPORTATION

CHAPTER 7

INTRODUCTION

The probability that hazardous wastes might be released accidentally during the transit of the Vulcanus from the pier at Chickasaw to the Gulf burn zone was described in Chapter 5. Although spills are very unlikely, they could involve relatively large quantities of waste. In addition, this type of release is unique to ocean-based incineration systems and has no direct parallel in land-based systems. Thus, we have included in our analysis an evaluation of the possible environmental and human health effects from spills of hazardous wastes into the marine environment.

IEc subcontracted with Applied Science Associates, Inc.(ASA) to analyze the pollutant transport and marine ecosystem effects that could result from a loss of cargo from the ship at three points along the vessel's transit path:

- in the Mobile Bay ship channel,
- over the continental shelf near the Mississippi River delta (29 degrees 45 minutes North and 88 degrees 30 minutes West), and
- in the center of the designated burn zone (26 degrees 40 minutes North and 93 degrees 40 minutes West).

Since the characteristics of the marine environment differ along the vessel's proposed path, analysis of the effects of spills in these three areas was necessary to determine the range of potential effects of accidental releases during the voyage to the burn area.1/

We asked ASA to evaluate three release quantities -- a loss of half a tank, a loss of two tanks and a loss of the entire cargo. As discussed in Chapter 5, the estimated overall spill rate for the Vulcanus is very low -- about 1 per 17,000 voyages or 1 per 1,200 operating years. The estimated spill rate for any particular location is even lower. Further, our analysis of the distribution of spill sizes suggests that about 80 percent of the time only one cargo tank will be affected. Casualties resulting in damage to two or to three or more cargo tanks would occur about 15 percent and 5 percent of the time, respectively. Thus, the probability for a release of cargo from one tank, two tanks, or three or more tanks in Mobile Bay is estimated to be on the order of one per 11,000, 67,000, and 200,000 operating years, respectively. Similar estimates for other locations are provided in Chapter 5.

The analysis in Chapter 5 indicates that the probability of a casualty affecting one or two tanks is very low and the probability of a casualty resulting in a complete loss of cargo is extremely low -- even less than the 1 in 200,000 operating years shown above for a loss involving 3 or more tanks. Nonetheless, we have estimated the potential effects from the loss of an entire cargo to bound the possible damage that could result from an ocean transportation release.

ASA's calculations were carried out for each of the two waste streams selected for this study:

1/Due to time and budget constraints, we have not evaluated the effects of releases in the pier area, Chickasaw Creek, or harbor. Information in Appendix C indicates that about 80 percent of spills in the pier and harbor area would be expected at the pier. We believe that containment or remedial actions undertaken as a response to spills at the pier are likely to substantially reduce the amount of contaminants remaining in the environment.

1. a waste containing 35 percent by weight of polychlorinated biphenyls (Arochlor 1254) and 65 percent non-hazardous material (it is expected that PCB concentrations in waste streams in the future will be in the 10 percent range), and

2. a waste containing 50 percent by weight of ethylene dichloride and 50 percent non-hazardous material.

The dispersion of a pollutant through the environment, particularly in the ocean, can be strongly influenced by the mixture of substances in which the pollutant is included and the resulting physical and chemical state of the pollutant when released. We asked ASA to ignore this "mixture" problem and simply calculate dispersion and effects for the two individual chemicals of interest. Although Arochlor 1254 is heavier than sea water and would be expected to sink, we have considered both "floating" and "sinking" cases to reflect the fact that the PCBs might be entrained in a lighter-than-water fraction that would float much like an oil slick.[2] Since ethylene dichloride is soluble in water, ASA calculated EDC concentrations assuming that the compound quickly dissolves and diffuses once released from the ship.

Along with the specific composition of the waste, the dispersion and ultimate effects of material released from the ship during an accidental spill would depend upon other factors, including the nature of the accident, weather and sea conditions at the time, and the effect of any mitigating actions carried out. We asked ASA to assume in their analysis that:

- the waste is released to the surface of the ocean at a single point, instantaneously;

- no mitigating activities are carried out; and

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[2] JRB Associates, Inc. tested seven samples of PCB liquid wastes to determine behavior in water. Four of the samples had specific gravities greater than seawater and sank readily, whereas three of the samples had specific gravities less than seawater and floated (See JRB Associates, Inc., *Expanded Modeling of Incineration at Sea Impacts: Gulf of Mexico*, Final Report, June 1, 1984, p. 2 - 32).

- weather and sea conditions reflect the annual average.

These assumptions simplify the analysis considerably. For example, the discussion in Chapter 5 indicates that the quantity of waste released and the speed of release depends on a variety of factors, such as the nature of the accident and the density of the material relative to seawater. Further, the amount of contaminants that remain in the marine environment after a spill depends on the extent to which spills can be contained and recovered.

Methods for containing and recovering floating spills include the use of floating booms to contain slicks and of skimmers to remove the slick from the surface. Techniques for recovering materials that sink include the use of hand held dredges, suction dredges, and hydraulic dredges. Such mitigating activities are likely to be most successful in the pier and Mobile Bay areas and least successful on the continental shelf and in the burn zone. However, evaluating the likely effectiveness of mitigating activities in removing contaminants from the marine environment was beyond the scope of this study. Our analysis of several release amounts provides information to bracket the likely effects of spills and to estimate the effects of various amounts of wastes remaining in the marine environment.

In addition to the analysis provided by ASA, IEc analyzed the potential for short term human health effects from a spill through inhalation of pollutants volatilized from the spill site. IEc's calculation of risks from spill volatilization is described in detail in Appendix H.

The remaining sections of this chapter describe the methods used by ASA and IEc and the limitations of these methods; and the dispersion, marine effects and human health effects from spills at each of the three sites. A more detailed discussion of ASA's data, methods, assumptions and results is provided in Appendix I.

METHODS AND THEIR LIMITATIONS

ASA used a computerized ocean transport model to estimate the movement of pollutants released over the continental shelf or in the burn zone. This model represents the Gulf of Mexico in square grids of size .25 degree, and uses data on average surface and subsurface current fields to move and disperse released material across the area. Mixing in the vertical dimension occurs through dispersion, settling, and (for shallow areas such as the continental shelf) resuspension due to wave action. Concentrations in the sediments for pollutants that settle assume perfect mixing to a depth of 5 centimeters.

In the case of a floating PCB spill, the waste material is assumed to be perfectly mixed in the top one meter of water and to be moved and dispersed only by the seasonally averaged surface currents and wind. In the case of a sinking PCB spill, all hazardous material is assumed to fall through the water column and reach the ocean floor. Some of the PCBs will sink rapidly to the sea floor, whereas others would settle at different rates depending on the settling velocities of particulate matter onto which they absorb. Accordingly, ASA used three different settling velocities (0.1, 0.01 and 0.001 m/s) and assumed equal amounts of PCBs would settle out at each velocity. In the EDC case, the material is assumed to dissolve and disperse rapidly. It is important to note that none of these calculations include the effects of weathering, volatilization or other physical or chemical reactions which might reduce concentrations in the water column or sediments.3/

Estimating the dispersion of releases in Mobile Bay for persistent materials, such as PCBs, is difficult. Among the factors that would influence the dispersion of materials in the short-term are the density of the material (sinking or floating spill), physical or chemical reactions of the material while in the water column, settling velocities, the location of the spill, wind speed and direction, and the direction and velocity of surface and subsurface currents. ASA developed a number of scenarios for the short-term dispersion of floating spills based on most probable wind speeds and directions in Mobile Bay. The long-term transport of PCBs in sediments was qualitatively assessed based on information on average hydrodynamic energy

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3/The JRB analysis cited previously indicates that only a small percentage of PCBs in a surface slick would volatilize and most of these would be the less chlorinated PCBs. Thus, we do not expect such processes to materially reduce the amount of PCBs remaining in the marine environment after a spill. However, a significant amount of EDC could volatilize if there were a spill, particularly in the shallow waters of Mobile Bay.

levels in the Bay. Estimates of the dispersion of spills that sink to the bottom of the Mobile ship channel are taken from the JRB analysis.

Once transport and dispersion of the hazardous constituent was calculated using the methods outlined above, ASA estimated the effects of the resulting water column and sediment concentrations on ten trophic levels of marine organisms found in Mobile Bay and the Gulf of Mexico. The trophic levels considered include:

- phytoplankton,
- benthic flora,
- benthic deposit feeders (e.g. mollusks),
- demersal detritivores (e.g. shrimp, crabs),
- herbivorous zooplankton,
- carnivorous zooplankton,
- small pelagic fish (e.g. menhaden, herring),
- large pelagic fish (e.g. tunas, sharks),
- benthic invertebrate predators (e.g. corals), and
- demersal fish (e.g. flatfish, deep sea species).

ASA used a computerized marine ecosystem model to estimate effects on these trophic levels. The model includes formulations of physiological and metabolic processes for each trophic level. Seasonal cycles are important in the areas of interest and are reflected in the ASA model. The ecosystems model estimates whether pollutant concentrations in the water column and in sediments are acutely toxic to marine species (in the event of sufficiently high concentrations) and estimates bioconcentration through the food web. Dose-response relationships for acute effects and bioconcentration factors were estimated by ASA from available data in the literature. Chronic marine effects (for example, changes in reproductive rates) due to long-term exposure to sublethal concentrations or to bioconcentration are not included due to lack of quantitative information relating cause and effect. A diagram showing the interrelationships among trophic levels in the model is provided as Exhibit 7-1.

ASA's analyses describe the effects of marine spills through the following measures:

1. physical descriptions of the dispersion of the hazardous constituent;

2. changes in the level of biomass in the area affected by the spill, reflecting the acute toxicity of the hazardous constituent to marine organisms as well as effects through the food web; and

3. changes in the tissue concentration of the hazardous constituent in each of the ten trophic levels to reflect bioconcentration and potential chronic effects.

The transport model delineates the area affected by the spill and estimates the contaminant concentrations in the sediments in this area. For the continental shelf and burn zone cases, sediment concentrations exceeding 1 ppb after settling of the pollutant are used to define the area over which the ecosystems model is run. Changes in the level of biomass and in tissue concentrations are calculated assuming that the pollutant is uniformly concentrated in the sediments over this area (the average concentration is calculated by dividing the amount of pollutant within the area by the volume of the top 5 cm of sediments within the area). Marine species are assumed neither to migrate into or out of the contaminated area.

For the Mobile Bay case, the ecosystems model was run assuming uniform concentration across the entire bay (calculated as a weighted average of contaminated and uncontaminated sediments). This simplification was necessary because there is insufficient information to predict accurately the long-term transport of PCBs in sediments and to assess how the feeding habits of marine species would affect bioconcentration if portions of the Bay were contaminated at different levels. In all analyses, biomass is estimated in units of milligrams of carbon per square meter of area. This can be converted to milligrams wet weight of living matter per square meter by multiplying by a factor of 20. As stated above, all of the methods and data used and the results obtained by ASA are explained in more detail in Appendix I.

In the event of a spill some hazardous constituents might volatilize and subsequently could be inhaled by humans causing possible short term health effects. We estimated the potential for such effects by estimating the rate of volatilization for each constituent for the first 24 hours following a spill and modeling downwind ambient concentrations. For the harbor and continental shelf spills, we used a simplified virtual point source air dispersion equation to calculate ground level downwind concentrations at the plume centerline. For the burn zone spill we adapted ASA's air dispersion modeling results (see Appendix G) to generate similar outputs. In all three cases, concentrations for the first 24 hours following a spill were calculated for the nearest point at which humans might be exposed, and the resulting estimates were compared with allowable limits for short-term exposure to the constituents of interest. Appendix H describes IEc's volatilization analyses in detail.

The models and methods used by ASA and IEc to estimate dispersion and effects from ocean transportation releases are by nature incomplete and uncertain.4/ The major strengths of these tools are that they:

- unify existing scientific knowledge into an internally consistent framework,
- force explicit recognition of assumptions and data sources, and
- allow investigation of the effect of alternative data, methods or policies on the results predicted.

4/The ASA model is the most comprehensive currently available. However, because it has only recently been developed, it has not yet undergone a comprehensive peer review.

Because of the extremely complex processes being analyzed and the significant scientific uncertainties that remain in many areas, the results obtained should be viewed as a general indication, rather than a precise measure, of pollutant transport and of potential effects. Ideally, these models and methods should only be used when time and resources allow extensive sensitivity analyses to be carried out, coupled with verification studies utilizing field measurements. Such studies have not been performed for the applications reported here. The marine models, however, have been run using data on background concentrations of PCBs in sediments and the water column and have yielded estimates of concentrations of PCBs in fish that generally agree with measured concentrations.

All of the methods and results are described in more detail in the appendices cited previously. These appendices also contain discussions of the specific limitations which pertain to each step of the analyses. All results should be interpreted with caution, and with a full understanding of all of the limitations.

MARINE EFFECTS OF A RELEASE OF PCBS IN MOBILE BAY

To analyze the effects of a release in Mobile Bay, we assume that the spill occurs in the ship channel at the point shown in Exhibit 7-2. Three release quantities are analyzed -- half a tank (88 metric tons of PCBs), two tanks (350 metric tons of PCBs), and the entire cargo (1,400 metric tons of PCBs). The paragraphs below describe the likely dispersion of the hazardous constituents and the potential ecological effects.

Pollutant Dispersion

A spill of PCBs would float or sink depending on its density relative to seawater. For the floating case, ASA assumed the spill would behave much like an oil spill and estimates its likely path using most probable wind directions and speeds for the Bay. Exhibit 7-2 shows the likely paths of spills occurring at low tide (the likely paths at high tide are shown in Appendix I). The path of the spill depends both on wind direction and water circulation, which is counter clockwise in the Bay. Case A reflects winds coming out of the north and Case B reflects winds coming out of the southwest. Since Case A represents a worst case in terms of the initial area affected by a spill (in the absence of efforts to contain the slick) and in terms of the Bay's retention of PCBs, we restricted further analysis to that case.

The amount of PCBs likely to settle out into sediments before the slick reaches the shoreline is difficult to estimate precisely. ASA estimates that from 30 to 70 percent of the PCBs could settle before reaching shore. We assume for further analysis that 50 percent of the PCBs become entrained in sediments on the floor of the Bay and the remaining 50 percent become stranded on the shoreline.

Exhibit 7-3 shows the area of the Bay's sediments initially affected by a spill of 8 tanks. As shown, about 15 percent of the floor of the Bay is affected. A spill of half a tank would affect about 5 percent and a spill of 2 tanks would affect about 9 percent of the floor of the Bay. Under the assumptions outlined above, the initial concentration of PCBs in the top 5 cm of sediments averaged over the contaminated zone would be about 13 ppm, 23 ppm, and 61 ppm for the half, 2 tank, and 8 tank spills, respectively.

The long-term dispersion of PCBs in the Bay is difficult to predict accurately. Data on net water circulation in the Bay suggest that resuspended PCBs would move generally northward and eastward on flood tides, though some PCBs could move out the mouth of the Bay on ebb tides. Marine organisms may also play a role in redistributing PCBs in the Bay. PCBs reaching the shoreline probably would gradually penetrate into the fine sediments and remain there for a long time.

PCB wastes with a density greater than seawater probably would sink to the bottom of the ship channel, although some could settle in shallower waters outside the channel depending on wind conditions. The distance the wastes would be transported away from the spill site would depend on the specific gravity of the material, the extent of adsorption onto particulate matter, and current direction and velocity at the time of the spill. Under maximum current conditions, JRB estimated that some PCBs could be transported as much as 7 to 18 kilometers from the spill site. However, most of the waste probably would settle out much closer to the spill site.

We have not attempted to evaluate the long-term dispersion of "sinking" spills nor effects on the marine environment. We expect that remedial actions would remove a substantial portion of the wastes and routine dredging of the ship channel each year by the Army Corps of Engineers would remove further amounts from the Bay. However, determining the likely effects of dredging activities on removal and resuspension of PCBs is beyond the scope of this study.

Marine Effects

Estimating the potential effects of spills in a complex estuarine ecosystem such as Mobile Bay is difficult at best. Nonetheless, to develop a general indication of the likely effects of PCB spills we asked ASA to make a number of simplyifying assumptions and then to apply their ecosystem model to the Bay. The modeling assumptions are fully described in Appendix I, but two of particular interest are (1) PCBs in sediments are assumed to be fully "available" to benthos (in terms of mortality response) and (2) marine organisms, on average, are assumed equally likely to feed in contaminated or clean areas. Since some PCBs are made biologically unavailable through binding with organic carbon in sediments, the modeled results tend to overstate biomass and bioconcentration effects.5/ Assuming "average feeding" allows the model to be run using an average PCB concentration in sediments across the entire Bay and tends to account for the potential spreading of PCBs over time.

Exhibits 7-4 and 7-5 present the model's estimates of the effects of a spill on the biomass of various trophic levels and on concentrations of PCBs in tissues. The results in Exhibit 7-4 indicate that benthic feeders and predators would be largely eliminated in the Bay. While this exhibit shows results for an 8 tank spill, results are similar for spills of one half and two tanks. Other trophic levels would not be significantly affected. However, the model predicts that PCB concentrations in marine organisms would increase by about 3 to 5 orders of magnitude

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5/Studies of the effects of PCBs in sediments on marine life in the Puget Sound and New York Bight areas indicate less adverse effects than normally would be expected. These preliminary findings suggest that the toxicity of PCBs can be reduced by organic carbon binding, but existing data are not sufficient to estimate precisely the extent of the reduction.

depending on the size of the spill. Exhibit 7-5 shows PCB concentrations increasing in small pelagic fish and shrimp by about 4 to 5 orders of magnitude (to tissue concentrations slightly in excess of 2 ppm) for a half tank spill. For larger spills, such as an 8 tank spill, tissue concentrations are estimated at about 15 ppm. These effects are expected to last for an extended period of time.

The above results represent an "average" across all of Mobile Bay. It is likely that portions of the Bay would be more or less contaminated than the average. Thus, some benthic species probably would survive in less contaminated areas. Avoidance of contaminated areas by marine species also could reduce average contamination levels. However, we have not attempted to determine potential adverse effects on spawning and nursery areas or on species in the affected low-lying marsh areas.

MARINE EFFECTS OF A RELEASE OF PCBS OVER THE CONTINENTAL SHELF

The continental shelf stretches roughly 100 to 150 kilometers offshore from the Gulf of Mexico coastline, and is defined by water depths less than 100 meters. These relatively shallow waters are rich in marine life and are important for both ecological and commercial reasons. To evaluate the consequences of a marine accident and spill in these waters, we modeled the dispersion and effects of a spill at a point near the mouth of the Mississippi River (29 degrees 45 minutes North and 88 degrees 30 minutes West). The paragraphs below summarize the results of the analysis.

Pollutant Dispersion

The dispersion of PCBs was calculated for both a floating and a sinking case. In the floating case, we assume that the PCBs would be confined to the top one meter of the water column and would be dispersed by surface currents and winds. The slick would spread to cover about two square kilometers within several hours of the spill, and then would break up into patches and disperse over a wider area. Assuming average wind and current, some portions of the slick would come ashore on the Mississippi delta while the remainder would move in a generally eastward direction. Exhibits 7-6 and 7-7 show the position of the slick at 10 and 50 days after the spill. (These exhibits show concentrations calculated for the release of the entire cargo; concentrations for lesser size spills would be proportionately lower than those shown and the area of dispersion of the slick would be slightly smaller.) After some time much of the PCBs probably would sink to the bottom of the continental shelf due to weathering, volatilization of the lighter hydrocarbons, and adsorption onto particulate matter. The actual behavior of the slick would be governed by the specific wind and sea states at the time of the spill.6/

In the sinking case, we assume that the PCBs would sink to the bottom and lodge in the top 5 centimeters of the sediments. Because of the relatively shallow depths at the assumed spill location, all the pollutant would reach the ocean floor within two days after the spill event. Thus, concentrations in the water column would be elevated for only a short time. Surface and subsurface currents would move and disperse the PCBs as they fall through the water column to the bottom. In addition, because of the relatively shallow depth of the continental shelf, the PCBs in the sediments would be continually resuspended by wave action and storm events. Thus, PCBs would continue to spread and disperse on the bottom for many years.

Maps provided as Exhibits 7-8 and 7-9 display the estimated extent of PCB-contaminated sediments at 1 and 10 years for an 8 tank spill. The area of contamination would be about the same for lesser size spills, but the concentrations would be proportionately less. Over time, sediments contaminated to levels greater than 1 ppb would include an area on the shelf of about 17,500 square kilometers.

6/An analysis performed by JRB estimates the percentage of spills occurring on different segments of the ship track that would come ashore (anywhere) in 3, 10 and 30 days. The analysis indicates that a very high percentage of spills occurring close to Mobile Bay would come ashore (over 90 percent within 10 days). This percentage becomes lower as the spill location moves further from Mobile Bay -- closer to the Mississippi delta area. For example, only about 15 to 30 percent of spills off the Mississippi delta are estimated to come ashore within 10 days. However, about 70 percent of these are estimated to come ashore within 30 days. (See the JRB study cited previously, pp. 2-7 to 2-10.)

Marine Effects

We have not quantified the effects on the marine ecosystem that a floating spill might have. A temporary effect of a PCB slick would be to interfere with the "microlayer" on the surface of the Gulf. Predicted concentrations of PCBs would be lethal to the organisms in the microlayer, but at this time data do not exist to quantify the role of the microlayer in the overall marine ecosystem. As PCBs leave the slick and settle on the ocean floor, the ecosystem effects expected would approach those predicted for the sinking case. Indeed, the area of the slick shown in Exhibit 7-7 corresponds fairly closely to the area of sediments contaminated by a sinking spill as shown in Exhibits 7-8 and 7-9. If the slick comes into contact with the shoreline, and PCBs still remain in it, significant, long-term coastal impacts are likely but have not been estimated.

Exhibits 7-10 and 7-11 summarize the marine ecosystem effects over the continental shelf predicted by the model for a one half tank spill of PCBs that sinks. As reported above, an area of sediment of roughly 17,500 square kilometers is likely to be contaminated. The results indicate that there probably would be a small decrease in the total biomass levels in the area, with benthic organisms suffering a substantial reduction. However, the major impact would be an increased level of PCBs in the tissues of most trophic levels -- as shown in Exhibit 7-11, most trophic levels experience an increase of from two to three orders of magnitude. Large pelagic and demersal fish would experience the greater increase, followed by small pelagic fish and demersal detritivores (e.g. shrimp and crabs). These levels of PCB contamination might cause chronic effects in the marine species. Spills of greater amounts are estimated to result in concentrations in tissues proportionately higher, i.e., four times greater for a 2 tank spill and 16 times greater for an 8 tank spill. The effects on the biomass of benthic organisms are also predicted to be more severe. Specific modeling results for these cases are shown in Appendix I.

There is substantial uncertainty concerning the length of time and concentrations at which PCBs would remain in the sediments. The increased PCB tissue concentrations projected in Exhibit 7-11 to last for only several years are based on the simplifying assumption made for modeling purposes that PCBs would be released from sediments linearly at a fixed rate over time. A decaying exponential release probably would be a more appropriate functional form. Under such an approach, the duration of PCBs in sediments and of the bioaccummulation effects would be much longer than shown in the exhibits.

MARINE EFFECTS OF A RELEASE OF PCBS IN THE BURN ZONE

The center of the Gulf of Mexico burn zone is located in 1,400 meters of water at 26 degrees 40 minutes North and 93 degrees 40 minutes West. At this position, the zone is approximately 315 kilometers south southeast of Galveston, Texas. To evaluate the consequences of a spill in the burn zone, we modeled the dispersion and effects of a spill at the center of the zone. The paragraphs below summarize the results of the analysis.

Pollutant Dispersion

As in the prior cases, the dispersion of PCBs was calculated for both a floating and a sinking case. In the floating case, we assume that the PCBs would be confined to the top one meter of the water column and would be dispersed by surface currents and winds. The spread of the slick would occur much as described for the continental shelf spill. Assuming average wind and currents, the slick from a burn zone spill would move generally westward. Some portion of the slick could come ashore within 50 days of release. However, most of the PCBs would sink to the ocean floor by this time due to weathering, volatilization of the lighter hydrocarbons, and adsorption onto particulate matter. Exhibits 7-12 and 7-13 show the position of the slick at 10 and 50 days after the spill. These exhibits show concentrations calculated for release of the entire cargo; concentrations for lesser spills would be proportionately lower and the area of dispersion of the slick would be slightly less. The actual behavior of the slick would be governed by the specific wind and sea states at the time of the spill.[7]

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[7] The JRB analysis indicates that about 22 percent of slicks originating in the burn zone would come ashore within 30 days. (See the JRB study cited previously, p. 2-10.)

In the sinking case for PCBs, we again assume that the PCBs would sink to the bottom and lodge in the top 5 centimeters of the sediments. Because we assume a distribution of sinking times, the PCBs would arrive at the bottom from 1 to 25 days after the spill event. Thus, concentrations in the water column are elevated for a longer time than in the harbor and shelf cases. Surface and subsurface currents move and disperse the PCBs as they fall through the water column to the bottom. Once on the bottom, resuspension is negligible due to the greater depths in the area.

Maps provided in Exhibits 7-14 and 7-15 display the extent of PCB-contaminated sediments at 1 and 25 days after an 8 tank spill. At 25 days all PCBs have reached the bottom and sediments contaminated to levels greater than 1 ppb would include an area of about 57,000 square kilometers. For lesser spills, the area of contamination would be about the same, but the concentrations would be proportionately less.

Marine Effects

We have not quantified the effects that a floating spill in the burn zone might have on the marine ecosystem. A temporary effect of a PCB slick would be to interfere with the "microlayer" on the surface of the Gulf. The possible effects of this interference would be similar to those discussed for the continental shelf spill. As PCBs leave the slick and settle on the ocean floor, the ecosystem effects would approach those predicted for the sinking case.

Exhibits 7-16 and 7-17 summarize the marine ecosystem effects modeled for a one half tank spill in the burn zone. As reported above an area of sediments of roughly 57,000 square kilometers would be contaminated. The results indicate that there probably would be a small decrease in the biomass of some benthic communities. The effects on benthic communities are estimated to be more severe for larger spills, as is shown in Appendix I. As shown in Exhibit 7-17, PCB concentrations are projected to increase slightly in only benthic species and bottom feeders. Larger spills are projected to increase PCB tissue concentrations in benthic species and bottom feeders by three to four orders of magnitude, but there is little effect on pelagic fish. As mentioned earlier, there is considerable uncertainty over the duration of PCBs in sediments and it is likely that the effects modeled for benthic communities would persist for fairly long time periods.

MARINE EFFECTS OF RELEASES OF EDC

ASA also analyzed the marine effects of releases of the entire cargo of EDC wastes in Mobile Bay, the continental shelf, and the burn zone. The behavior of EDC in the marine environment is very different from that of PCBs -- it is highly soluble, it is volatile, it is not highly toxic, and it does not bioaccumulate. The net effect of these characteristics is that spills of EDC have very little adverse effect on the marine environment.

For a spill of EDC in Mobile Bay, we assume that all the material would go into solution and would rapidly disperse throughout the bay. The initial concentration would be about 700 ug/l. However, flushing of the bay and volatilization would rapidly reduce EDC concentrations, so that within 50 days the concentration of EDC would be virtually zero. The relatively brief elevated water concentrations would cause a brief increase in marine tissue concentrations of EDC. These tissues would return quickly (roughly 60 days) to background levels. As no acute toxic effects are expected, the marine effects of the EDC spill are likely to be transient and relatively minor.

The effects of spills of EDC over the continental shelf and in the burn zone are similar to the effects in the bay, though the initial concentrations and their duration are less. Consequently, marine effects of an EDC spill in either of these locations are likely to be transient and minor.

HUMAN HEALTH EFFECTS OF SPILLS OF PCB AND EDC WASTE

To evaluate short-term human health risks resulting from a spill, we have compared the possible concentrations of volatilized PCBs and EDC to the short-term exposure limit (STEL) and the Threshold Limit Value (TLV) for these chemicals. The STEL represents the maximum concentration to which workers can be exposed for short periods without suffering irritation, tissue damage or narcosis. The TLV represents the concentration to which workers may be repeatedly exposed without adverse acute effects. We have adjusted the TLV values used for EDC and PCBs downward to reflect continuous exposure rather than exposure for a 40-hour work week.

Atmospheric concentrations of PCBs and EDC are calculated in Appendix H. We estimated the rates of volatilization of each material in the three spill locations and modeled downwind ambient concentrations using average and "worst case" meteorological assumptions.

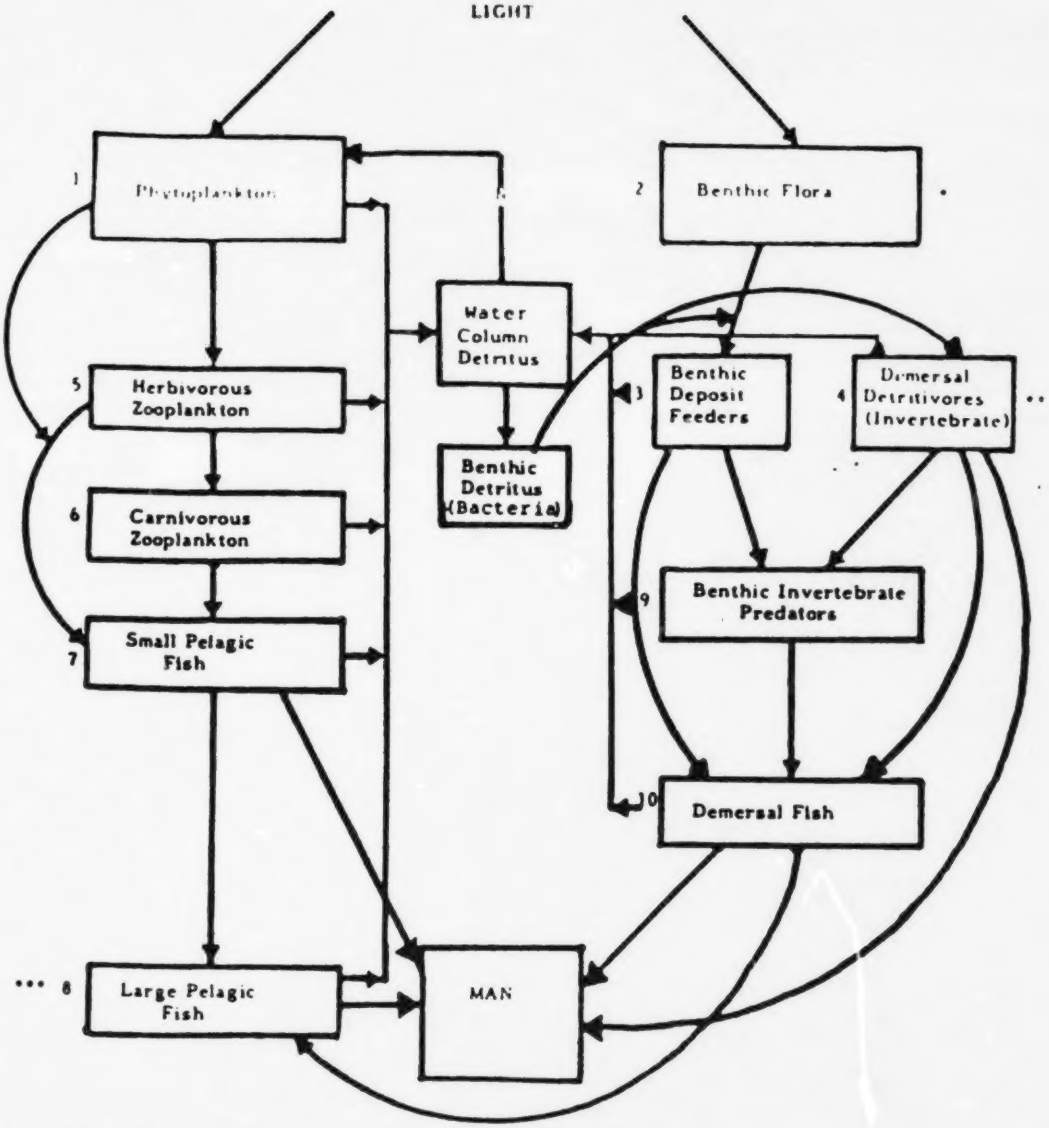
Exhibit 7-18 displays the ratios of these calculated air concentrations to the STEL and adjusted TLV values. As this exhibit shows, concentrations of both PCBs and EDC exceed adjusted TLV when the spill occurs at 1 km from Mobile. Only under worst case meteorological conditions would the concentrations of EDC exceed the STEL. For the spill at 15 km from the city, only EDC under worst case meteorological conditions would exceed the TLV. The ratios of concentrations of PCBs or EDC due to spills over the continental shelf or in the burn zone are far below one. In view of the fact that the population would be exposed to volatilization from a spill for period of a week or more, the adjusted TLV is the most appropriate threshold to consider. Thus, it is likely that only for spills closer than 15 km would air concentrations be of concern from a human health standpoint.

SUMMARY

This chapter presents our estimates of the dispersion of pollutants and resulting marine and human effects from releases during ocean transportation. As stated in the Introduction, it is important to understand that these releases are unlikely to occur and that attempts to characterize the possible effects of such releases have many limitations. Overall, the results show that PCB spills in Mobile Bay would have extremely severe consequences for the marine ecosystem. PCB spills over the continental shelf could significantly harm the ecosystem, whereas spills in the burn zone would have lesser effects, limited to benthic communities and to bottom feeders. In contrast, EDC spills do relatively little damage to the marine ecosystem. Short-term human health effects from inhalation of volatilized wastes are unlikely, except in the case of an EDC spill very close to Mobile. All of these results are explained further in Appendices H and I.

Exhibit 7-1

SUMMARY OF ENERGY (CARBON) FLOW IN THE ECOLOGICAL MODEL AS APPLIED TO THE GULF OF MEXICO


LIGHT
1
Phytoplankton
2
Benthic Flora
*
Water Column Detritus
Benthic Detritus (Bacteria)
3
Benthic Deposit Feeders
4
Demersal Detritivores (Invertebrate)
**
5
Herbivorous Zooplankton
6
Carnivorous Zooplankton
7
Small Pelagic Fish
9
Benthic Invertebrate Predators
10
Demersal Fish
***
8
Large Pelagic Fish
MAN

* Only Mobile Bay

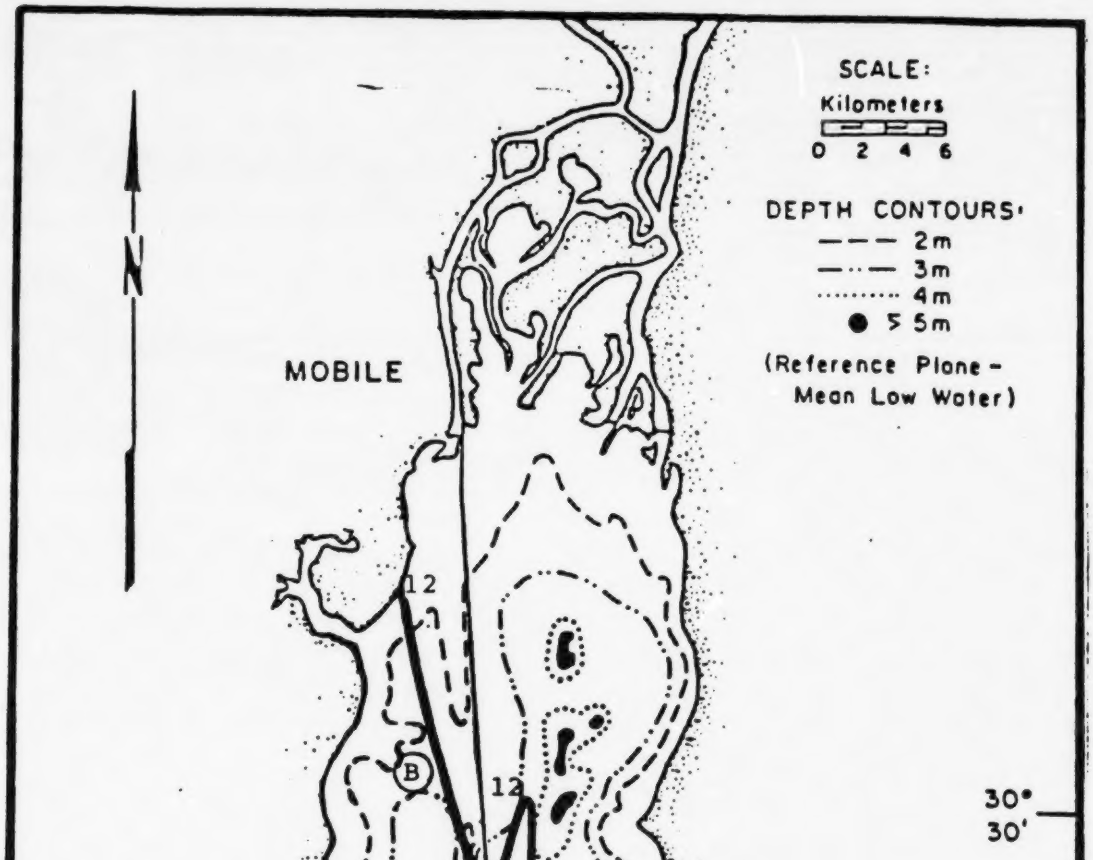
** Only Mobile Bay and Shelf

*** Only Shelf and Offshore

Source: Appendix I, Figure 3-1

Exhibit 7-2

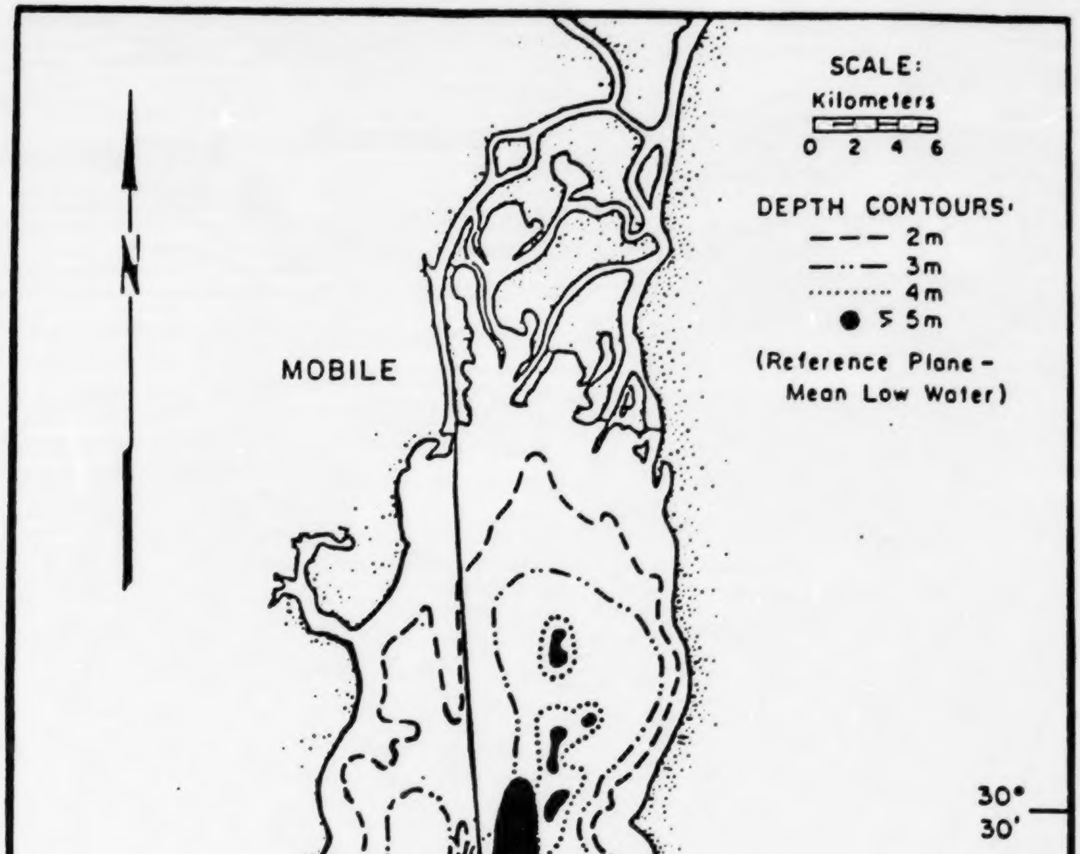
PROJECTED PATH OF SPILLS OCCURRING IN MOBILE BAY AT LOW TIDE


SCALE:
Kilometers
0 2 4 6
DEPTH CONTOURS:
2m
3m
4m
5m
(Reference Plane - Mean Low Water)
N
MOBILE
12
B
12
Main Ship Channel
36
A
24
2m
Dauphin Island
Main Pass
30° 30'
88°
GULF OF MEXICO

Source: Appendix I, Figure 6-3a

Exhibit 7-3

AREA OF BAY SEDIMENTS INITIALLY AFFECTED BY A FLOATING SPILL (CASE A)

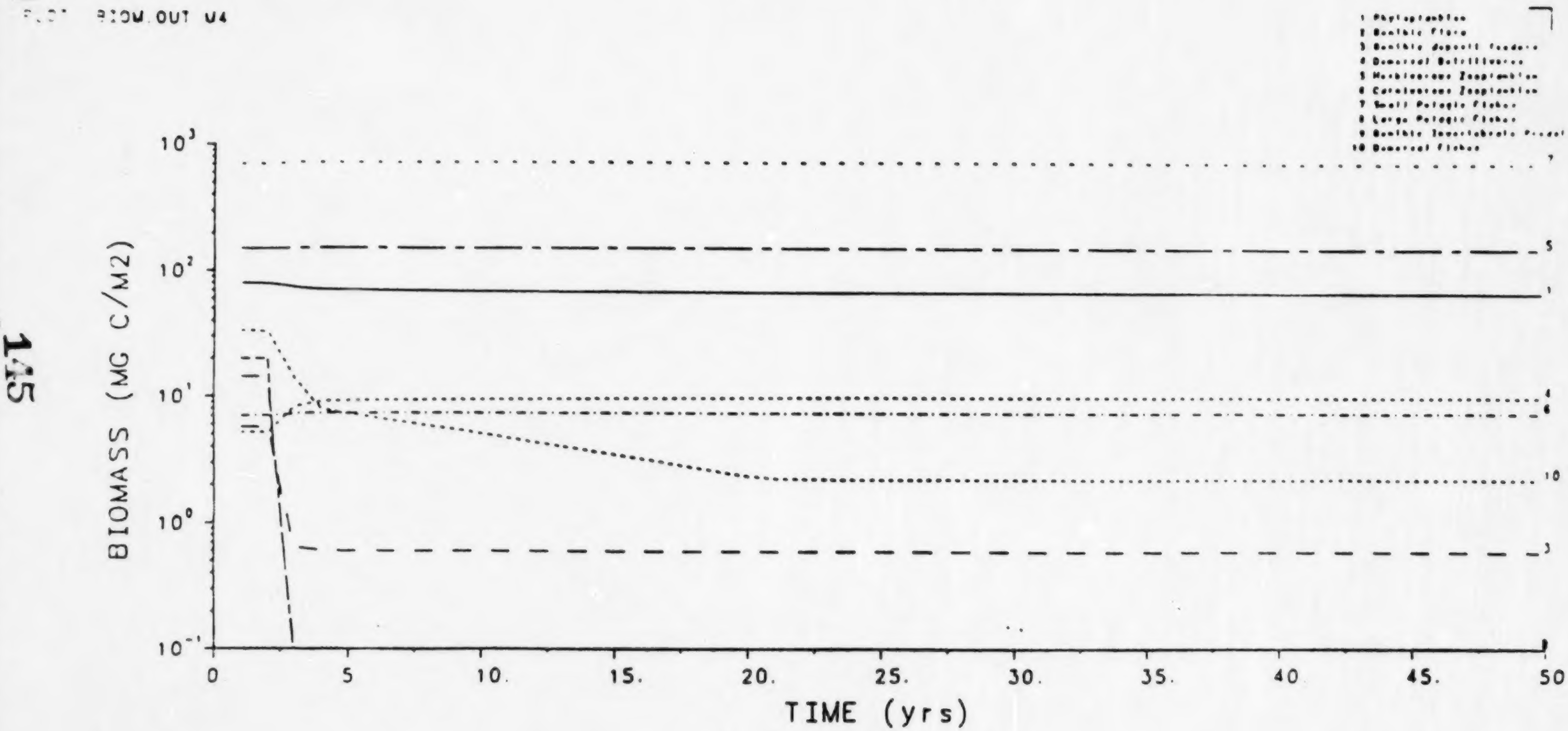

SCALE:
Kilometers
0 2 4 6
DEPTH CONTOURS:
2m
3m
4m
≥ 5m
(Reference Plane - Mean Low Water)
N
MOBILE
30° 30'
>2m
Douphin Island
Main Pass
88°
GULF OF MEXICO

Source: Appendix I, Figure 6-3d

Exhibit 7-4

PROJECTED BIOMASS LEVELS IN MOBILE BAY AFTER A SPILL OF AN ENTIRE CARGO OF PCBS

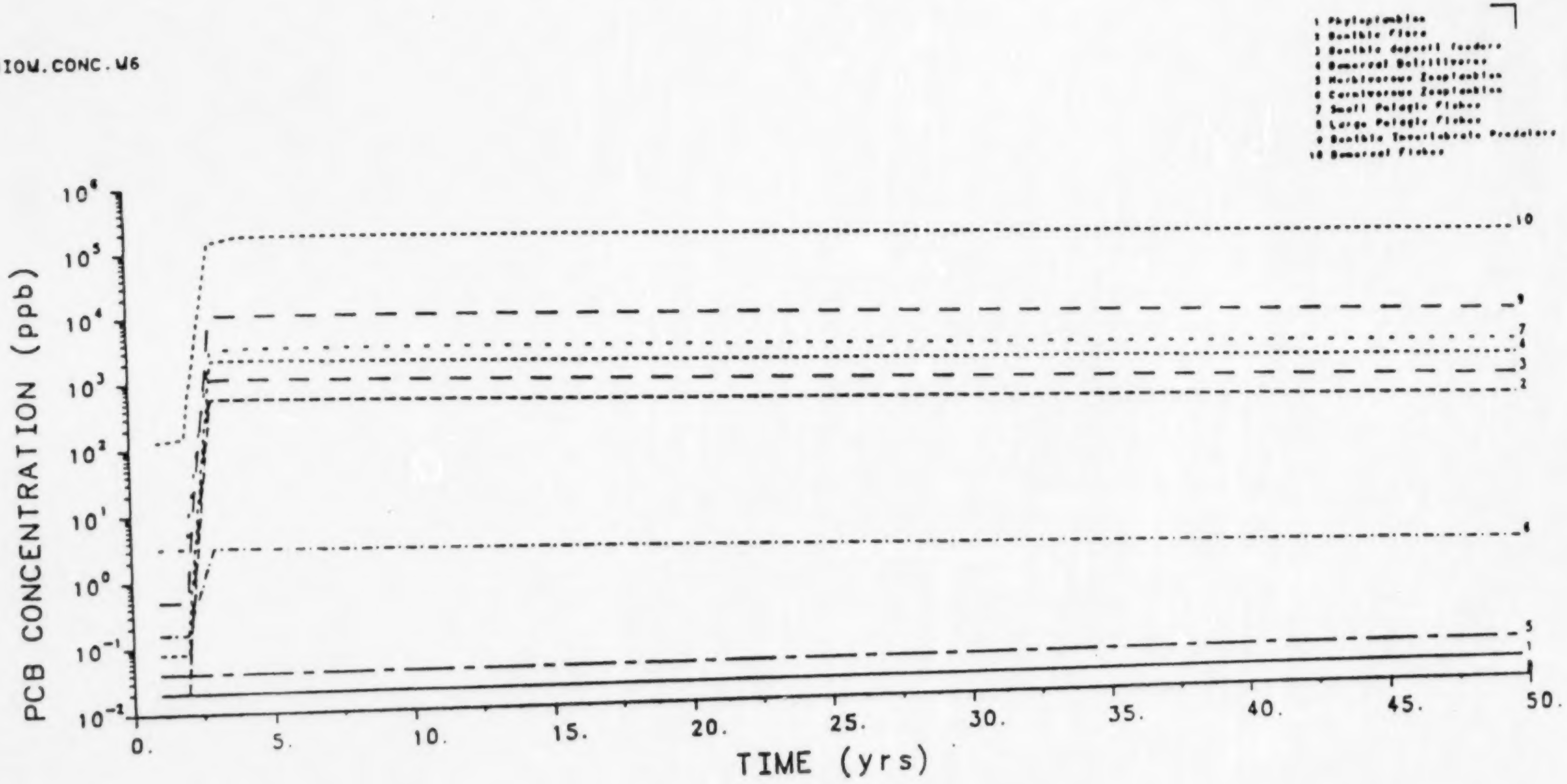
Reproduced from best available copy.



Source: Appendix I, Figure 6-4a

Exhibit 7-5

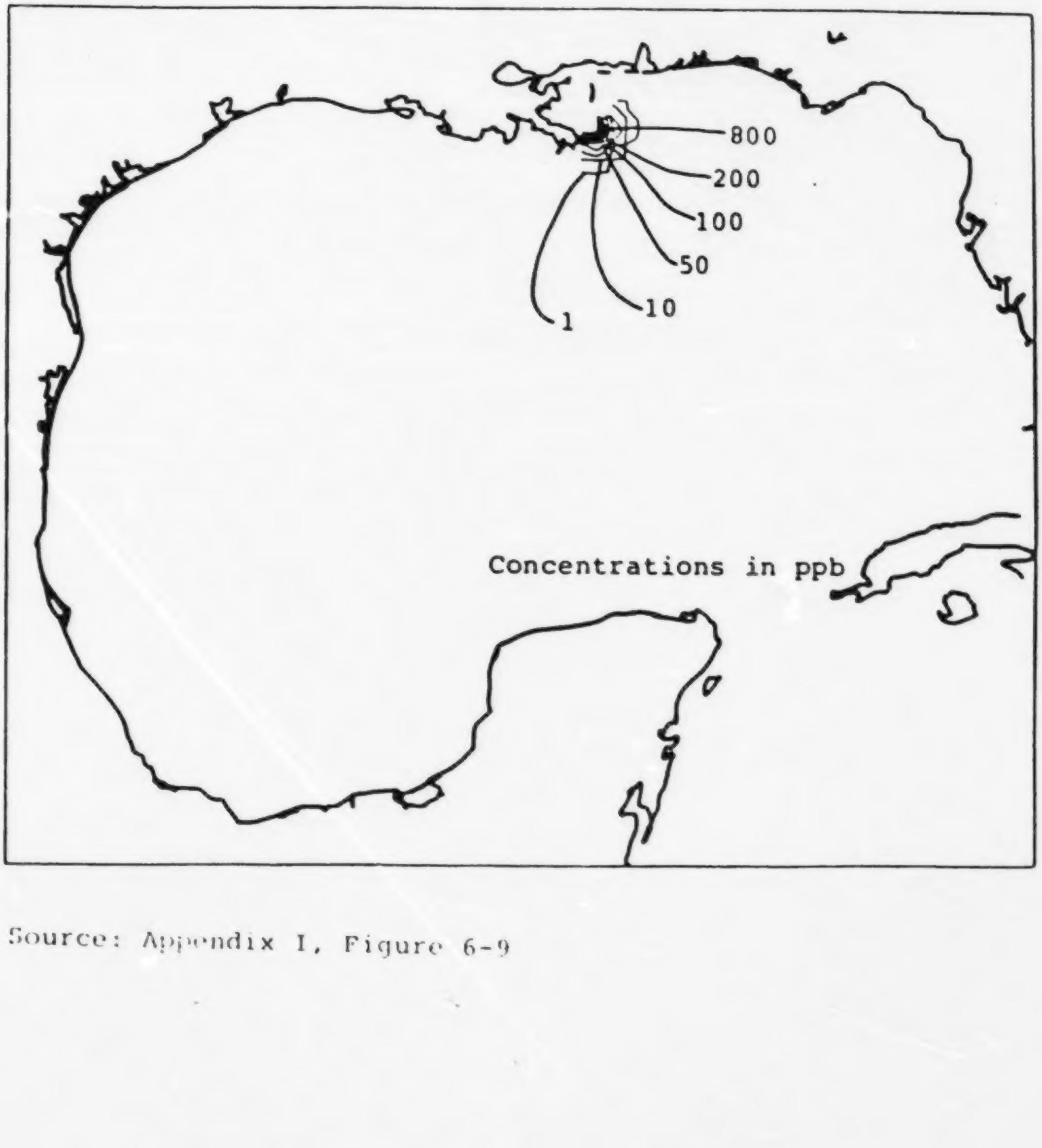
ESTIMATED PCB CONCENTRATIONS IN TISSUE AFTER A HALF TANK SPILL OF PCBS IN MOBILE BAY



Source: Appendix I, Figure 6-4d

Exhibit 7-6

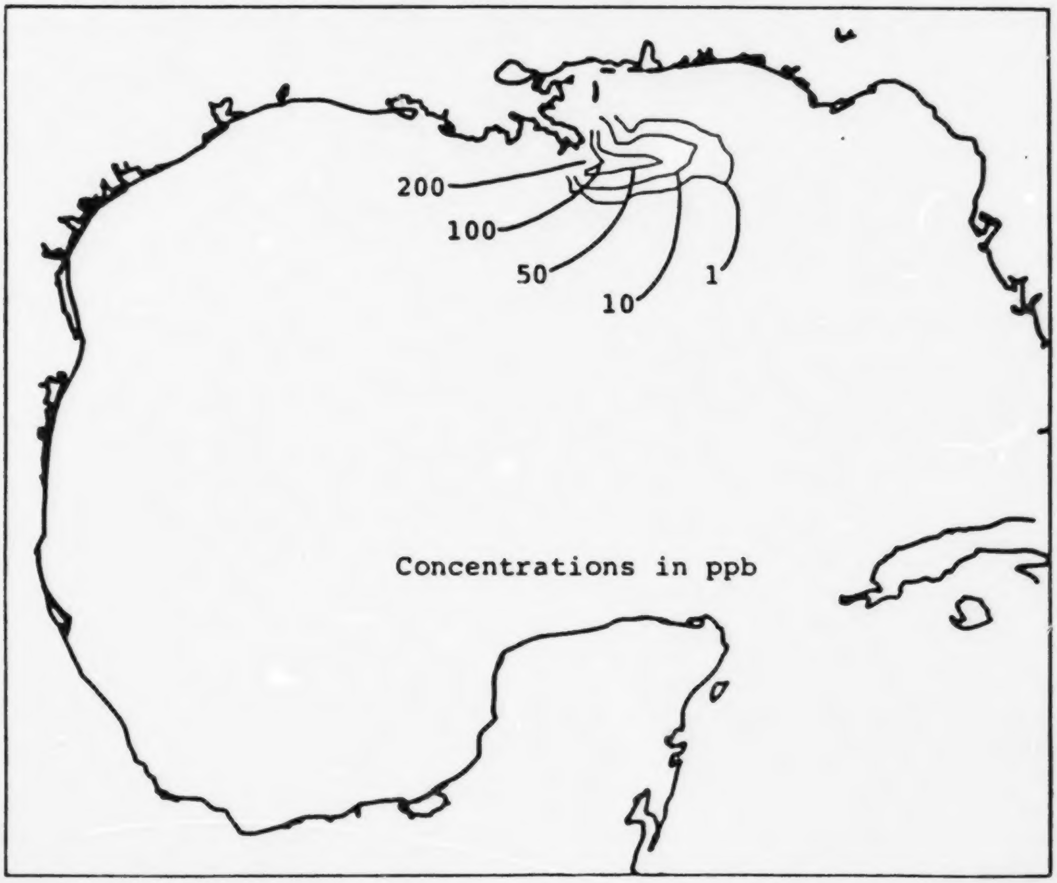
GULF OF MEXICO -- SPILL ALONG SHIP TRACK ON SHELF
10 DAY PCB CONCENTRATIONS AT WATER SURFACE
ASSUMES NO SETTLING OF POLLUTANT


800
200
100
50
10
1
Concentrations in ppb

Source: Appendix I, Figure 6-9

Exhibit 7-7

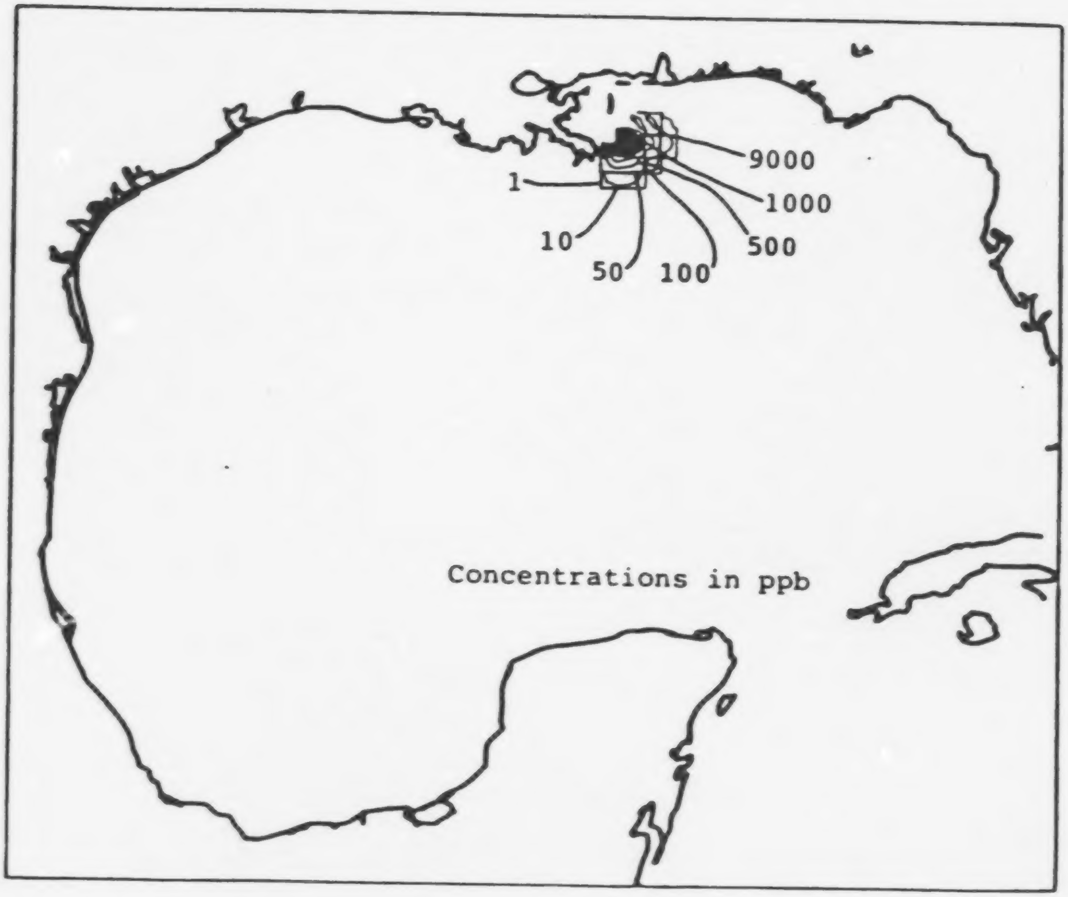
GULF OF MEXICO -- SPILL ALONG SHIP TRACK. ON SHELF
50 DAY PCB CONCENTRATIONS AT WATER SURFACE
ASSUMES NO SETTLING OF POLLUTANT


1
200
100
50
10
1
Concentrations in ppb

Source: Appendix I, Figure 6-10

Exhibit 7-8

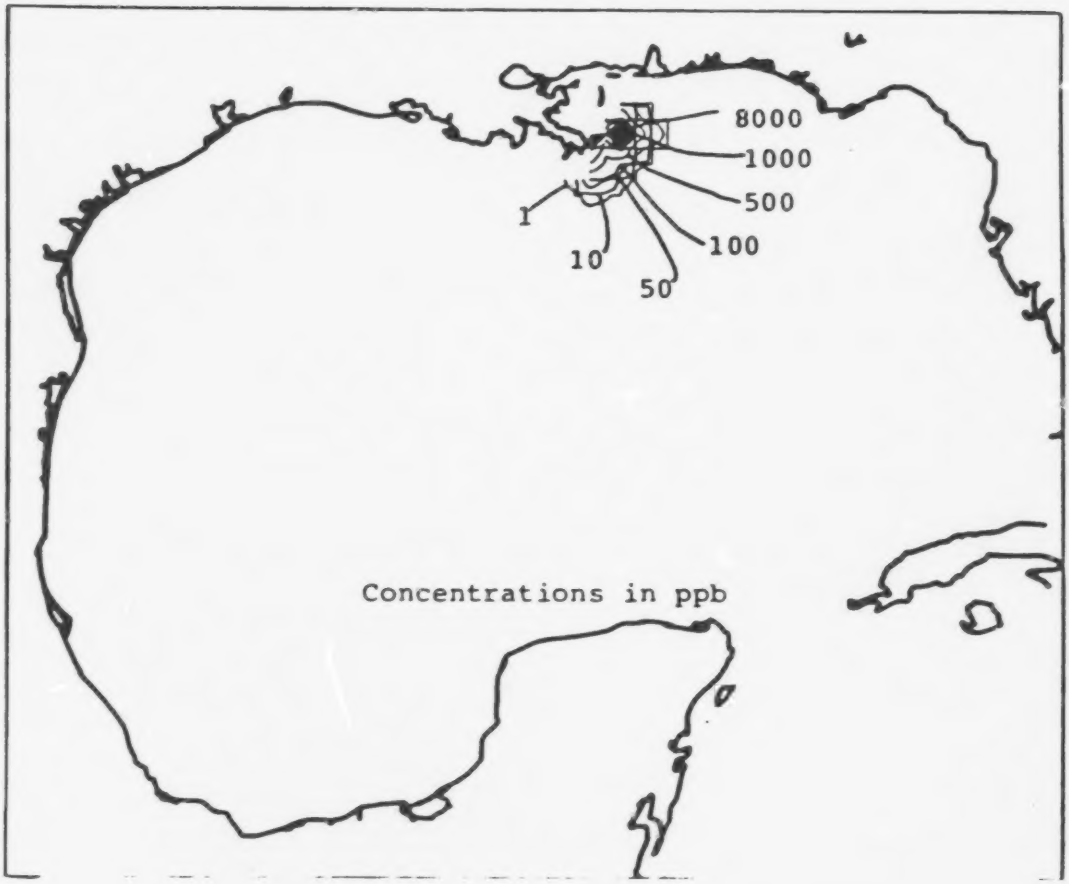
GULF OF MEXICO — SPILL ALONG SHIP TRACK. ON SHELF
1 YEAR PCB CONCENTRATIONS ON BOTTOM
ASSUMING VARIABLE SETTLING VELOCITIES


9000
1000
500
100
50
10
1
Concentrations in ppb

Source: Appendix I, Figure 6-5a

Exhibit 7-9

GULF OF MEXICO — SPILL ALONG SHIP TRACK. ON SHELF
10 YEAR PCB CONCENTRATIONS ON BOTTOM
ASSUMING VARIABLE SETTLING VELOCITIES

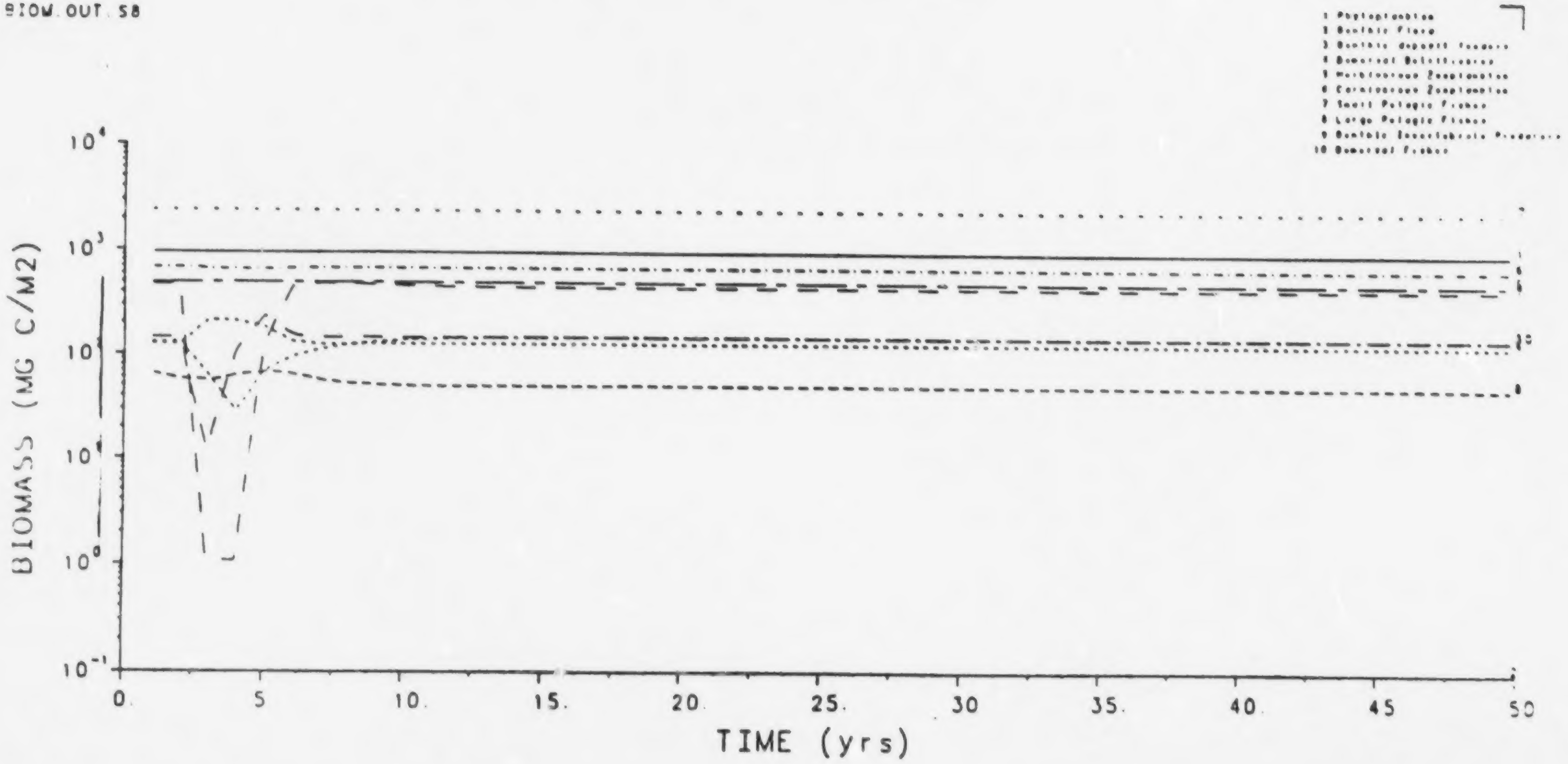

8000
1000
500
100
50
10
1
Concentrations in ppb

Source: Appendix I, Figure 6-6a

Exhibit 7-10

PROJECTED BIOMASS LEVELS AFTER A HALF TANK SPILL OF PCBS OVER THE CONTINENTAL SHELF

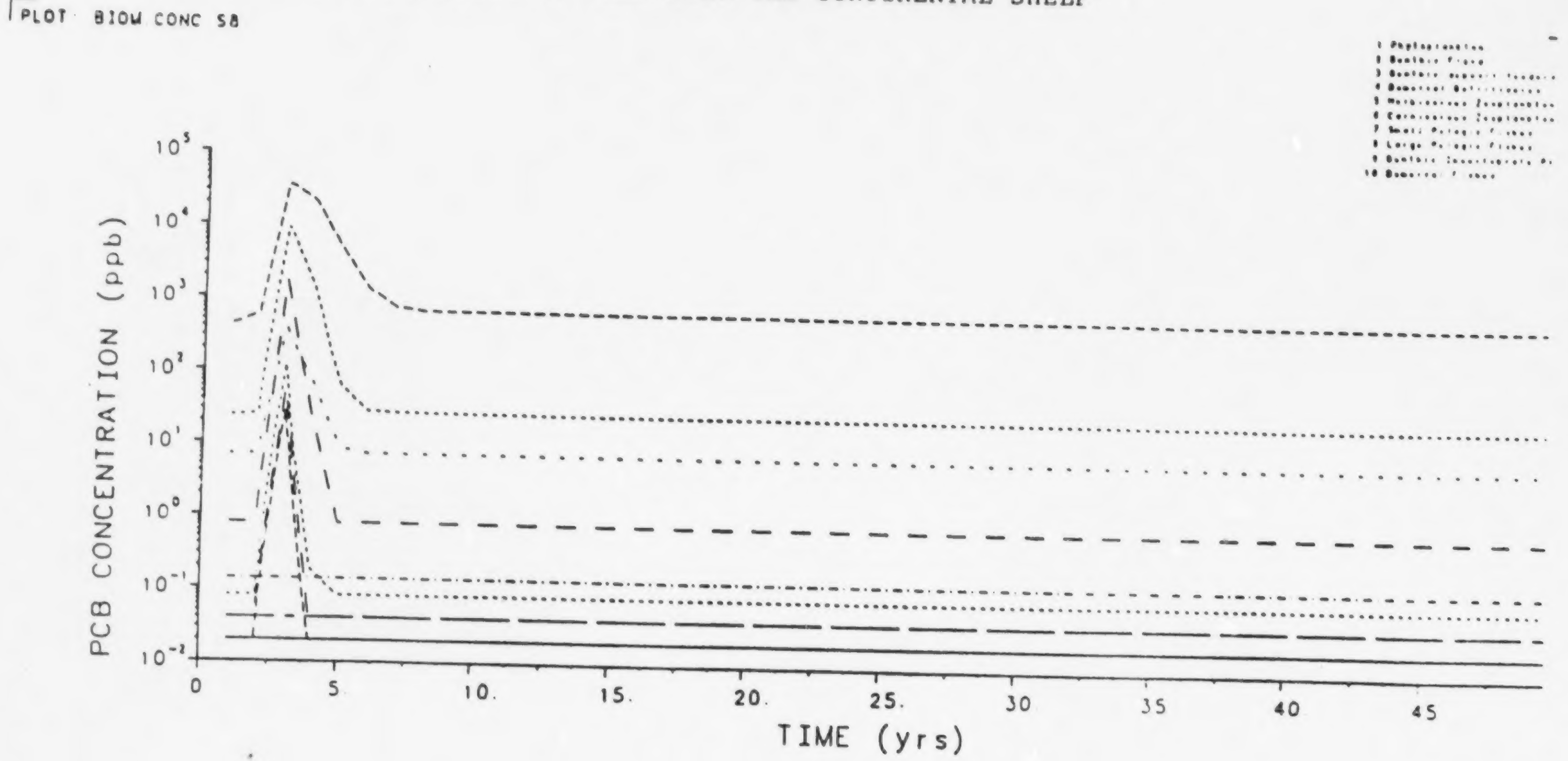
PLOT BIOW.OUT.58



Source: Appendix I, Figure 6-16d.

Exhibit 7-11

ESTIMATED PCB CONCENTRATIONS IN TISSUE AFTER A HALF TANK SPILL OF PCBS OVER THE CONTINENTAL SHELF

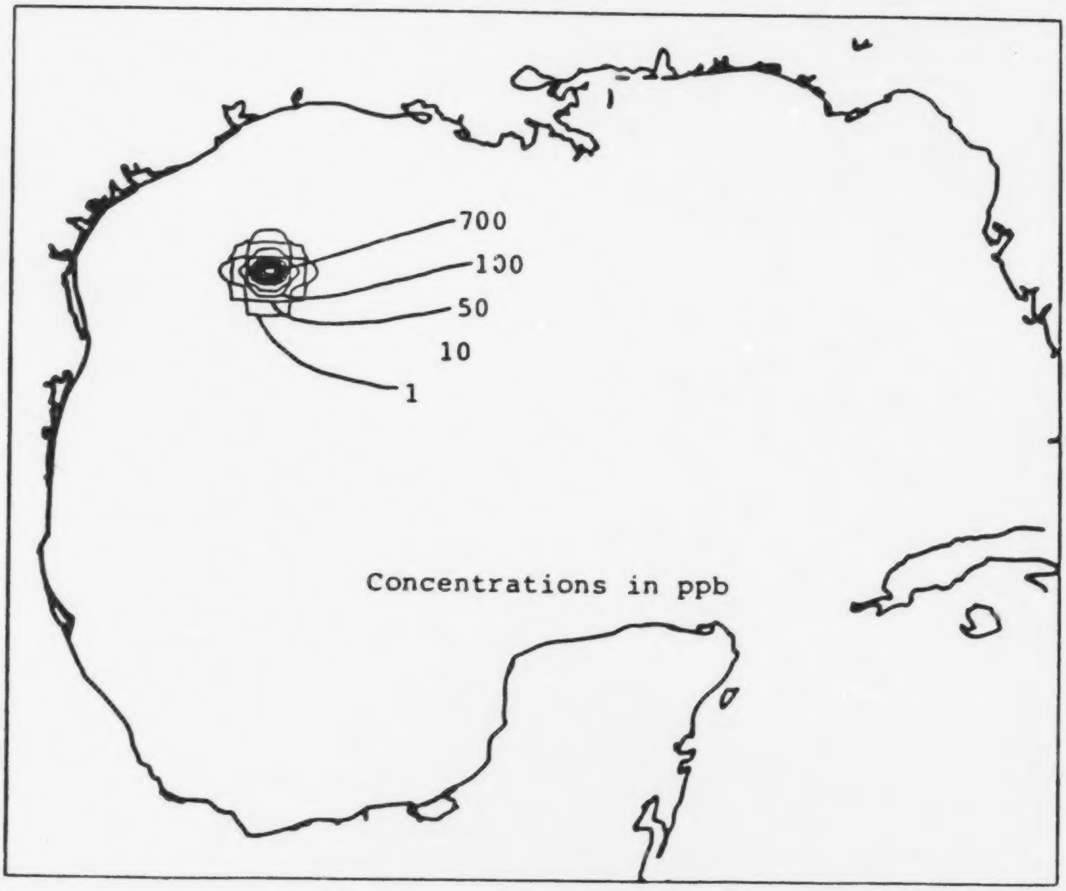


Source: Appendix I, Figure 6-15c.

Exhibit 7-12

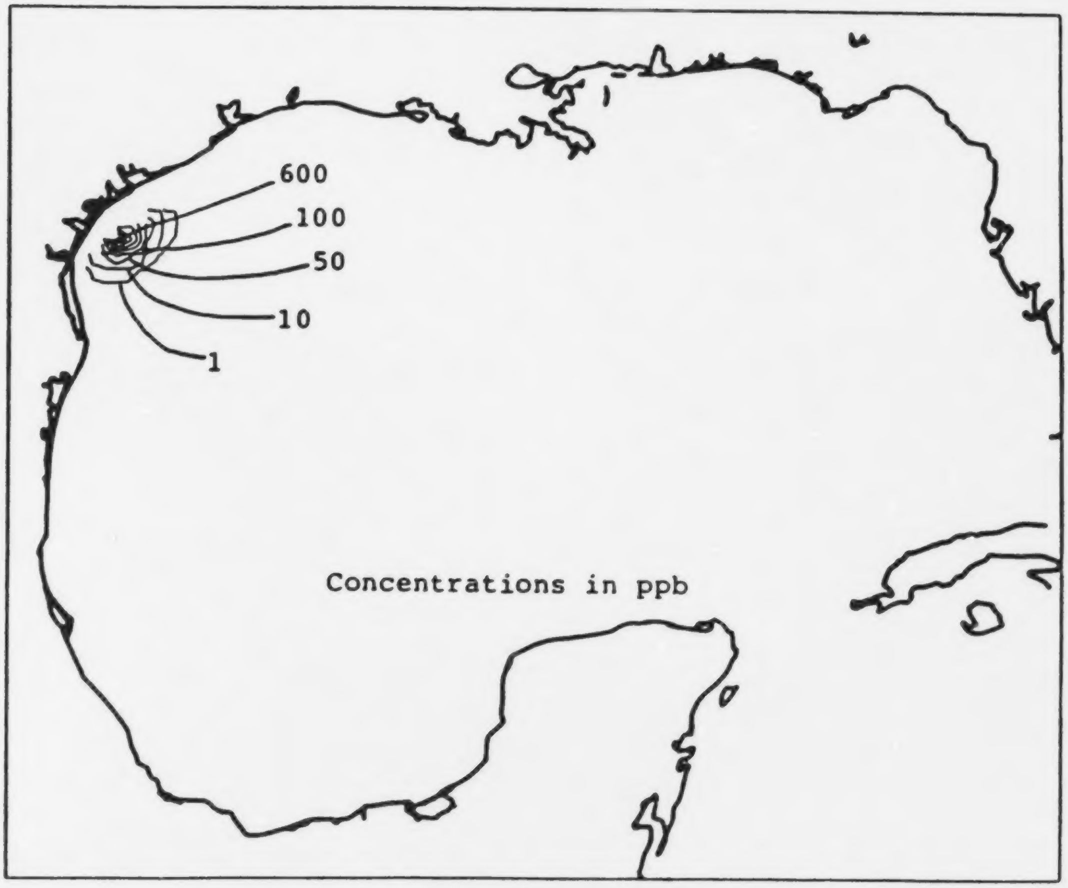
GULF OF MEXICO -- INCINERATION SITE SPILL

10 DAY PCB CONCENTRATIONS AT WATER SURFACE
ASSUMES NO SETTLING OF POLLUTANT


700
100
50
10
1
Concentrations in ppb

Source: Appendix I, Figure 6-20

Exhibit 7-13



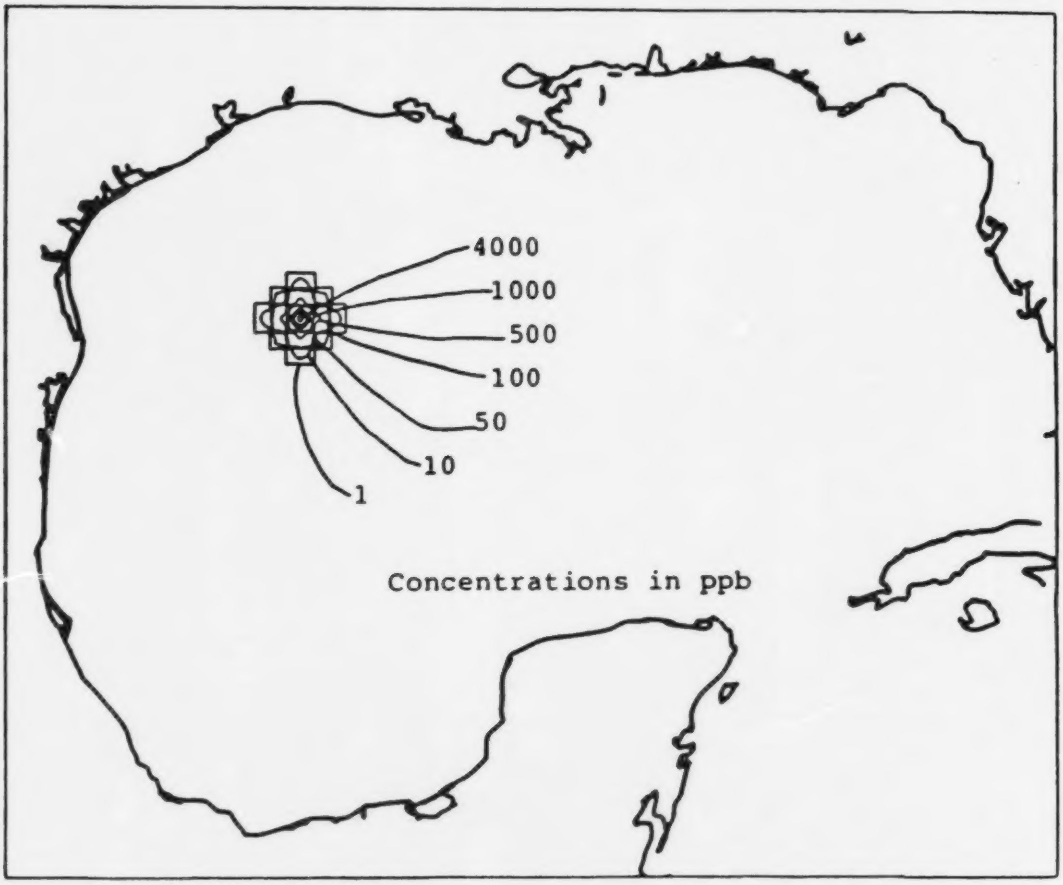
GULF OF MEXICO -- INCINERATION SITE SPILL
50 DAY PCB CONCENTRATIONS AT WATER SURFACE
ASSUMES NO SETTLING OF POLLUTANT

600
100
50
10
1
Concentrations in ppb

Source: Appendix I, Figure 6-21

Exhibit 7-14

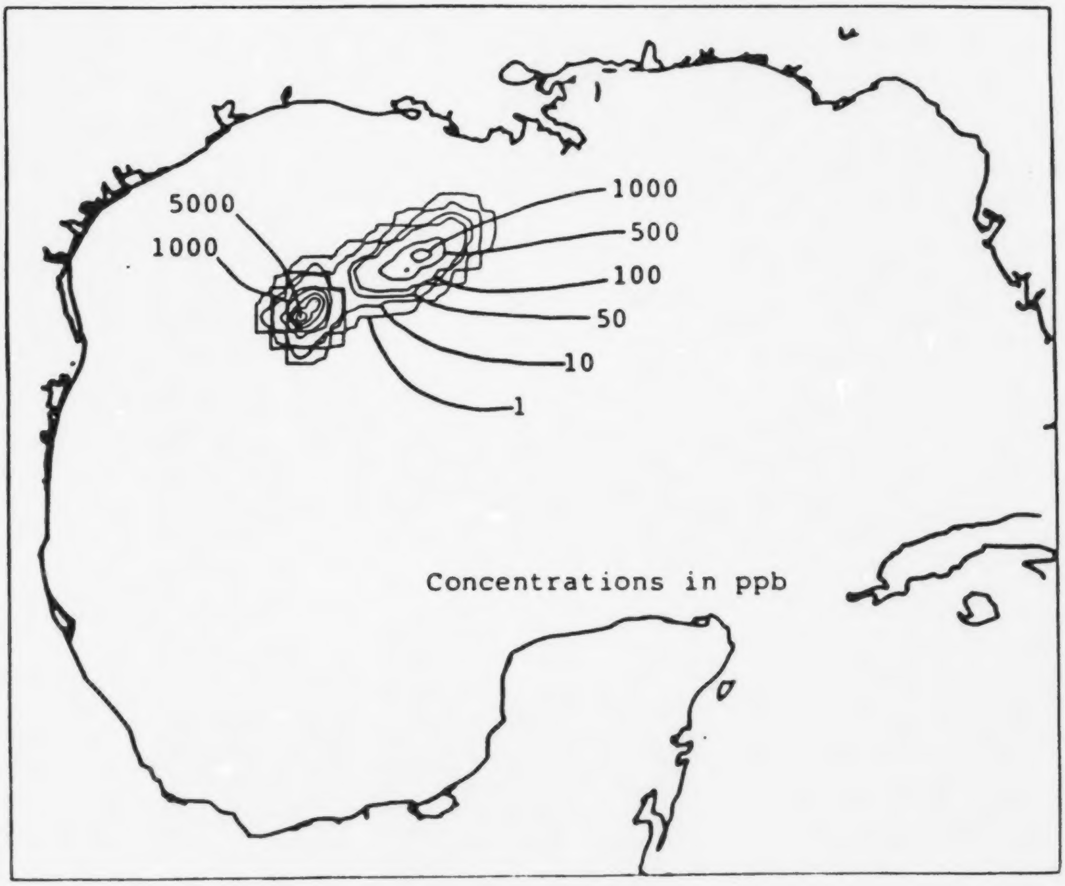
GULF OF MEXICO -- INCINERATION SITE SPILL
1 DAY PCB CONCENTRATIONS ON BOTTOM
ASSUMING VARIABLE SETTLING VELOCITIES


4000
1000
500
100
50
10
1
Concentrations in ppb

Source: Appendix I, Figure 6-17a

Exhibit 7-15

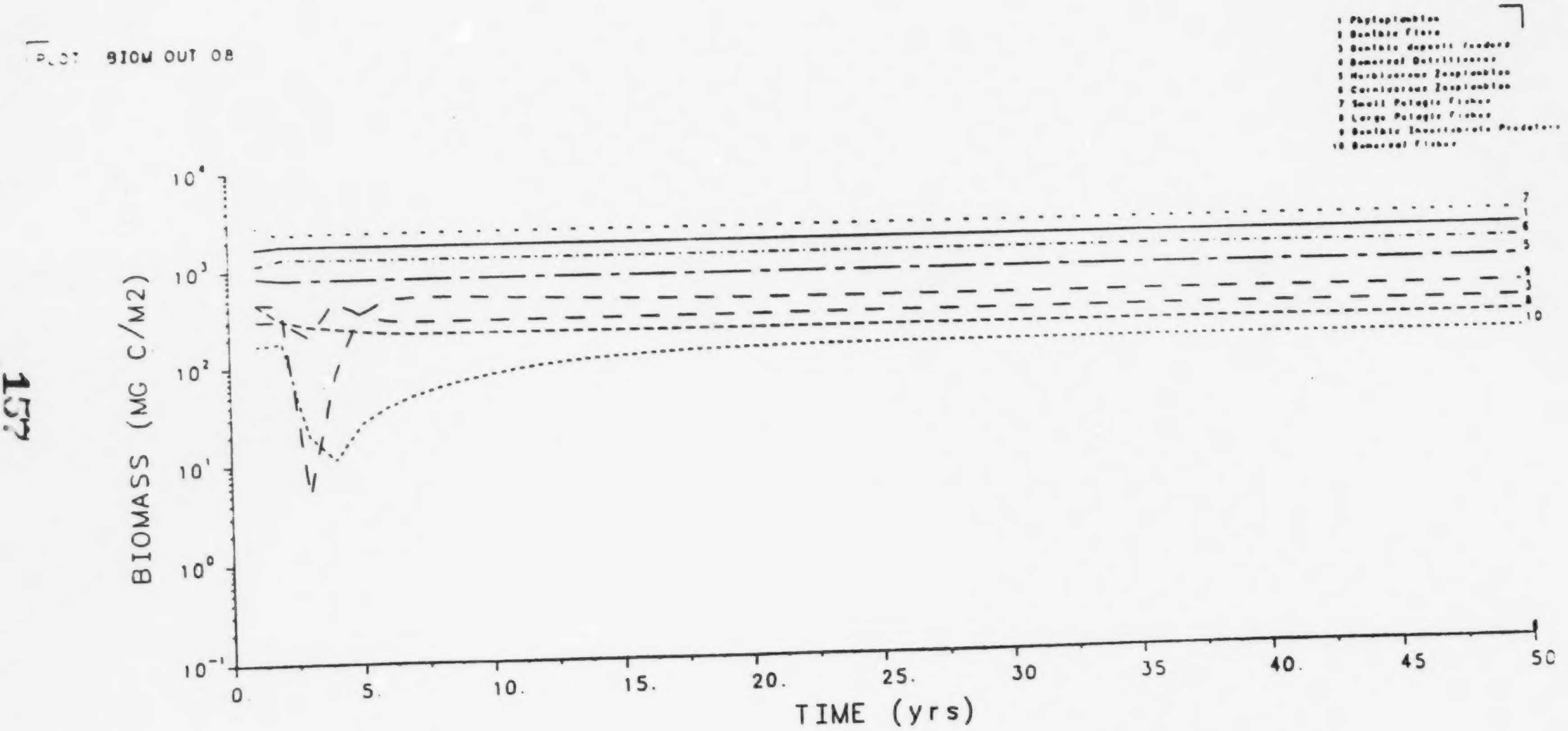
GULF OF MEXICO -- INCINERATION SITE SPILL
25 DAY PCB CONCENTRATIONS ON BOTTOM
ASSUMING VARIABLE SETTLING VELOCITIES


5000
1000
1000
500
100
50
10
1
Concentrations in ppb

Source: Appendix I, Figure 6-19a

Exhibit 7-16

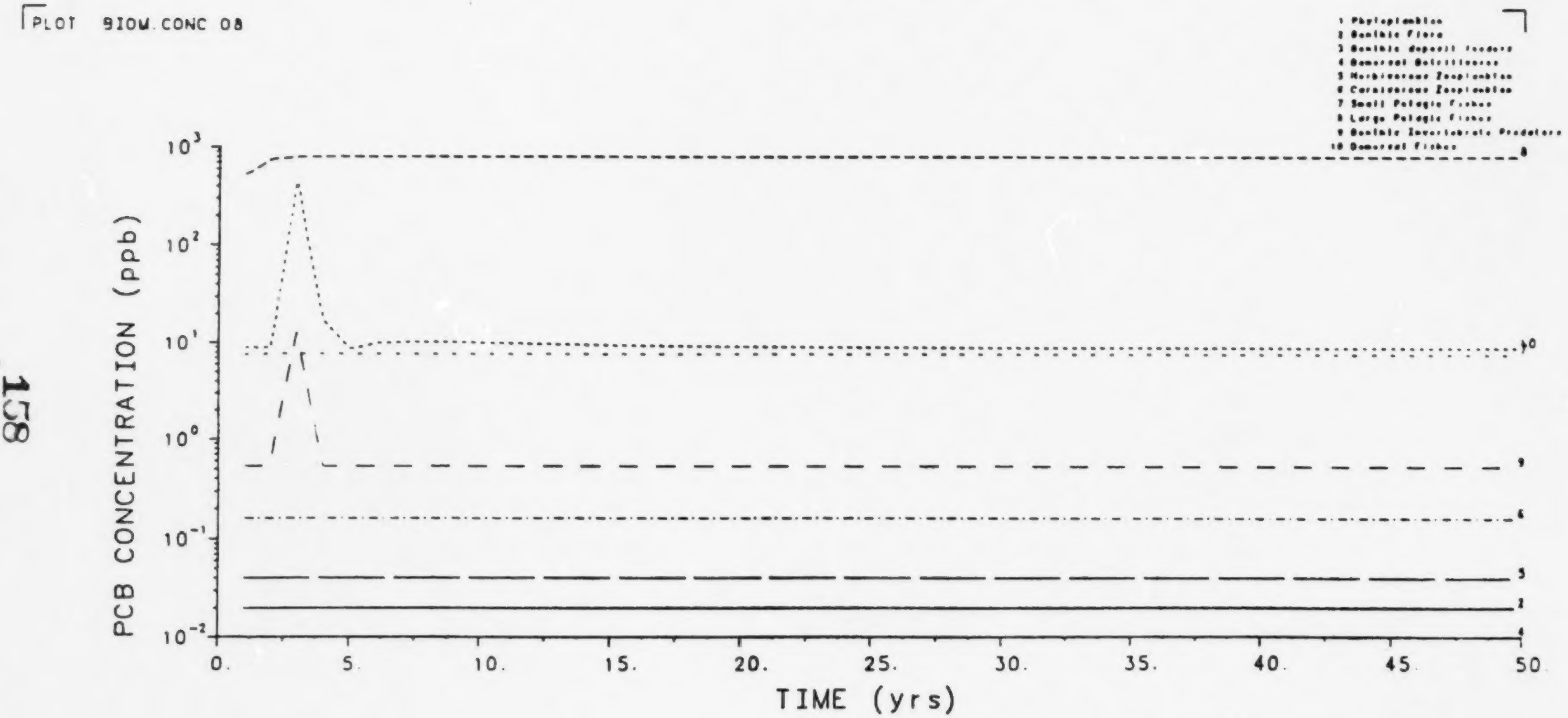
PROJECTED BIOMASS LEVELS AFTER A HALF TANK SPILL OF PCBS IN THE BURN ZONE



Source: Appendix I, Figure 6-26d.

Exhibit 7-17

ESTIMATED PCB CONCENTRATIONS IN TISSUE AFTER A HALF TANK SPILL OF PCBS IN THE BURN ZONE



Source: Appendix I, Figure 6-25c.

Exhibit 7-18

RATIOS OF AIR CONCENTRATIONS TO SHORT-TERM LIMITS

Waste and Atmospheric Conditions	- Mobile Bay - 1 Km	15 Km	Continental Shelf	Burn Zone
STEL				
PCB Waste				
Average	0.2	0.01	0.003	0.0008
Worst	0.3	0.03	0.021	--
EDC Waste				
Average	0.4	0.03	0.0003	0.00009
Worst	3.8	0.33	0.004	--
TLV				
PCB Waste				
Average	1.3	0.06	0.019	0.005
Worst	1.9	0.19	0.13	--
EDC Waste				
Average	1.9	0.12	0.002	0.0004
Worst	18.3	1.6	0.017	--

Source: Appendix H, Exhibits H-11, H-12

EFFECTS OF RELEASES FROM INCINERATION

CHAPTER 8

INTRODUCTION

The quantity and composition of hazardous materials released from ocean- and land-based incineration systems are described in Chapters 3 through 6. As shown in those chapters, large quantities of waste are released from incineration operations for both ocean- and land-based incineration systems. For this reason, we investigate and compare possible effects from these releases. This chapter describes the results of this work.

We estimate both human and environmental effects that could result from incinerator releases. For human populations we estimate the incremental risk of developing cancer through inhalation of atmospheric concentrations of hazardous materials from incinerator releases. In addition, for stack releases from land-based incineration we consider possible human health effects resulting from ingestion of food contaminated by deposition of pollutants on crops and subsequent bioconcentration in livestock and poultry. In the ocean incinerator case we perform a similar analysis for ingestion of pollutant-contaminated fish.

We also consider the possible environmental effects of incineration releases, albeit at a lower level of effort and resulting accuracy. For ocean-based stack releases, Applied Science Associates, Inc. (ASA) characterized quantitatively the possible effects resulting from deposition to the ocean surface of POHCs, metals and chlorine. For land-based stack releases, Arthur D. Little, Inc. (ADL) characterized the capture of metals and chlorine in scrubber waters and the possible environmental effects of final disposal of scrubber effluent and sludge. No work has been completed to date on the effects of land-based POHCs, PICs or metals on terrestrial or marine ecosystems.

All of the transport and effects estimates presented in this chapter are calculated wherever possible using methods and data developed or approved by EPA. Our use of these methods attempts to:

- unify existing scientific knowledge into an internally consistent framework,
- force explicit recognition of assumptions and data sources, and
- allow investigation of the effect of alternative data, methods or policies on the results predicted.

Ideally, such methods should only be used when time and resources allow sensitivity analyses of results to be completed and compared to field verification studies. Such studies have not been completed for the applications reported here. Thus, all of the results obtained are uncertain, and should be viewed as general characterizations of the transport and effects possible from incineration releases. The sections below and supporting appendices provide a discussion of the limitations that pertain to each step of the analysis. All results should be interpreted with caution and with a complete understanding of all of these limitations.

The remaining sections of this chapter describe the human health effects expected from ocean-based and land-based incinerator releases, and then review the environmental effects from each of these release points. The final section provides a brief summary and comparison of the results obtained for the two incineration systems.

HUMAN HEALTH EFFECTS

Our estimation of human health effects via inhalation for ocean- and land-based systems includes three steps:

1. estimation of atmospheric concentrations due to stack releases,
2. calculation of resulting doses received by humans, and
3. calculation of the increase in cancer risk if human populations received these dosage levels over a 70 year lifetime.

Each of these steps and associated interim results are presented in detail in Appendix D (land-based systems) and Appendix G (ocean-based systems). Although we calculate a variety of concentration and health risk metrics in the appendices, the discussion in the sections below is limited to the increase in cancer risk for the most exposed individual (MEI). Risks for the MEI are the highest estimated for any person and thus provide an upper bound on the individual risk increases likely from inhalation of incinerator releases.

All human health effects are estimated assuming that the population is exposed over a 70 year lifetime. Thus, in these calculations the annual incinerator release quantities presented in Chapters 3 through 6 are assumed to continue for 70 years. Although it is unlikely that incinerator operations and the resulting releases will remain constant over such a long time horizon, data and methods to predict human effects from shorter exposures to chronic levels of these pollutants are not available.

Ocean-Based Incineration

The atmospheric transport of POHCs, PICs and metals released from the stack of the Vulcanus operating in the center of the Gulf of Mexico burn zone was estimated by Applied Science Associates, Inc. (ASA) using a numerical model of monthly surface winds in the Gulf. The model incorporates two atmospheric removal processes -- washout due to rainfall and dry deposition. Washout is modeled as a stochastic process based on long-term weather observations in the Gulf. Dry deposition is a function of the settling velocity of the pollutant. All pollutants that come into contact with the ocean surface are assumed to be absorbed by it. Dispersion modeling results are based on an average mixing height in the western Gulf between 1000 meters (winter) and 2000 meters (summer). Ambient air concentrations of POHCs, PICs, and metals at coastal locations are estimated for each month of the year.

ASA's transport results show that the position of the plume changes monthly due to changes in the prevailing winds. Thus, no single area of the coast is exposed continuously throughout the entire year. Further, differences in the variability of wind direction within the months alter the concentration levels expected and the duration of exposure. To estimate worst case exposure levels, ASA identified the location on the Gulf coast that receives the highest modelled concentrations averaged over a year from ship releases in the burn zone. This occurs at approximately 24.5 north latitude and 97.8 west longitude, on the coast near Brownsville, Texas. IEc used ASA's air modeling results to determine health risks to a hypothetical "most exposed individual" at this maximum dose location.

We use the cancer unit risk factors published by EPA's Carcinogen Assessment Group for the POHCs, PICs and metals found in the plume to calculate the increase in lifetime cancer risk experienced at the MEI annual dosage level. These incremental lifetime risks assume continuous exposure for 70 years and are calculated for a 70 kilogram adult. The results of these calculations are summarized in Exhibit 8-1.

As shown in Exhibit 8-1, the hypothetical most exposed individual incurs total increased risk of cancer of 6.4 in ten million for the PCB waste and 1.1 in one million for the EDC waste. For both wastes, over 99 percent of this increased risk results from exposure to metals emitted from the stack. Incremental risks for persons living at other locations on the coast will be even lower.

Although the risks from metals are dominant in our analysis, note that these results are sensitive to our assumptions about metals concentrations. MEI risks would be lower for waste streams having significantly lower concentrations of carcinogenic metals. In addition, the results are sensitive to the settling velocity assumed for metals. For modeling purposes, metals emitted from the stack are assumed to rapidly take on the characteristics of background metal particles in the atmosphere. These background particles are small, approximately 1.5 micrometers, and have slow settling velocities. If plume sampling indicates metals emitted from the Vulcanus have higher settling velocities than the background particles, MEI risks from metals could be lower.

In addition to these calculations of human health risks from stack emissions, we analyze the risks possible through inhalation of releases from transfer and storage of wastes at Chickasaw. We use EPA's Atmospheric Transport Model (ATM) with meteorological data for the Chickasaw area to estimate air concentrations out to a 50 kilometer radius, assuming that the fugitive emissions are released from a single point source. (Information about the ATM model and our use of it is included in Appendix D.) The concentrations predicted and the aggregate population exposure are presented in Exhibit 8-2. For comparison, this exhibit also includes the exposure estimates for fugitive emissions at the land-based incinerators considered in this study.

Given the concentration for the maximum exposed individual at Chickasaw as shown in Exhibit 8-2, we calculate the incremental risk of cancer for the MEI assuming 70 years of exposure. These estimates are shown on the bottom line of Exhibit 8-3. Exhibit 8-3 also includes the results presented in Exhibit 8-1 for purposes of comparison. As this exhibit shows, releases from Chickasaw result in incremental risks from 2 in 100,000,000 to 5 in 10,000,000,000 for both waste streams, i.e., at least one order of magnitude lower than the risks from stack emissions of metals. Note that the location of the most exposed individual differs for ocean-based stack emissions and for releases from Chickasaw. No person at a single location would experience both of these risk levels.

In addition to direct inhalation of stack, storage or transfer releases, it is possible that human populations could ingest foods contaminated by these releases. ASA characterizes the effect that deposition of incinerator stack emissions could have on pollutant concentrations in the water column or ocean sediments, and the subsequent bioaccumulation of pollutants in fish and other compartments of the marine ecosystem. The analysis focuses on PCBs, the pollutant of interest that is most likely to bioaccumulate in marine life, and examines the effect of incineration of PCB wastes at sea over a 50-year period. The results of the analysis suggest that at the expected PCB emission rate there will be no observable change in the concentrations of

PCBs in fish, shrimp or other Gulf marine life.1/ As a result, seafood consumers would not face an increased cancer risk due to deposition of stack emissions.

Land-Based Incineration

The atmospheric transport of POHCs, PICs, and metals released from land-based incinerator stacks was estimated by IEc for incinerators located in Arkansas and Texas. In addition, we model the transport of transfer and storage emissions released from these sites. Texas and Arkansas are selected as "typical" locations because incinerators located at these sites are currently permitted to burn PCBs. Also, these sites show variations in meteorology, stack parameters and the size of the surrounding population.

The analysis of risks from land-based incineration closely parallels the incinerator ship analysis. The primary difference between the ocean- and land-based analyses relates to the volume of metals emissions. We assume that the land-based incinerators are equipped with scrubbers which are capable of removing some of the metals from the stack gases. The removal effectiveness of scrubbers is a function of the size of metal particles in the stack gases. For very volatile metals, such as arsenic, the removal efficiency of scrubbers is low. For less volatile

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1/To facilitate scaling the results to different levels of incinerator performance, the ASA analysis presented in Appendix I is based on a PCB emission rate of one kilogram per hour. At this rate, PCB concentrations in some trophic levels -- including demersal fish and shrimp, staples of the Gulf commercial fisheries -- are predicted to increase by more than an order of magnitude above background concentrations, posing an increased cancer risk to seafood consumers. However, the one kilogram per hour emission rate is more than two orders of magnitude greater than the expected emission rate -- 5.25E-3 kilograms per hour given a 99.9999 percent DRE. According to ASA, the increased concentration of PCBs in marine species is approximately linearly related to the emission rate. Therefore, at the expected emission rate, ASA expects no observable change in the concentration of PCBs in fish, shrimp and other Gulf marine life.

compounds, removal efficiency is higher. Analysis of trial burn data suggests that metal emissions can range from less than one percent to as much as 50 percent of the metals in the waste feed. For the purposes of this analysis, we assume 50 percent of the arsenic (a relatively volatile metal) in the waste feed is emitted in the stack gases and 10 percent of the chromium, cadmium and nickel. The possible environmental effects resulting from the ultimate disposal of the scrubber effluent and sludge are discussed in a later section of this chapter.

Our analysis of pollutant dispersion from the Texas and Arkansas sites uses the ATM atmospheric dispersion model developed for EPA's Office of Toxic Substances by researchers at Oak Ridge National Laboratory. ATM is a Gaussian plume climatological model linked to 1982 census data and to meteorology data from 394 weather stations in the United States. We use the model to determine atmospheric concentrations and resulting human exposures within 50 kilometers of each incinerator site. As in the analysis of ocean-based systems, we assume both wet and dry deposition. Wet deposition is based on average annual rainfall at each of the sites, and dry deposition is a function of the settling velocity for gases and particles. Our use of the ATM model is explained in Appendix D.

As in the ocean-based case, we use the cancer potency factors published by EPA's Carcinogen Assessment Group for the POHCs, PICs, and metals found in the stack gases to calculate the increase in lifetime cancer risk experienced by the most exposed individual. These incremental risks assume continuous exposure for 70 years and are calculated for a 70 kilogram adult. The results of these calculations are summarized in Exhibit 8-4 and explained in further detail in Appendix D.

As shown in Exhibit 8-4, the most exposed individual incurs total increased risks of cancer ranging from 2 to 3 in 100,000 for the PCB waste and from 3 to 4 in 100,000 for the EDC waste. Risk levels do not differ greatly for the two locations modeled. At both sites, metals account for at least 90 percent of the total risk. Risks from POHCs, PICs, and fugitive emissions are approximately an order of magnitude lower than risks from metals. Because the overall estimate of risk is determined by the volume of metal emissions from the incinerator, the results are sensitive to our assumptions about the quantity of metals emitted in the stack gases. If the removal efficiencies of scrubbers are higher than those assumed here, risk from metals is decreased. Analysis of the trial burn data, however, suggests that it is unlikely that removal efficiencies would be higher by more than an order of magnitude. This, in turn, would result in metal risks approximately ten times lower than those in Exhibit 8-4 reducing the overall incremental risks of land-based incineration to roughly one in a million.

In addition to the human health risks from inhalation presented above, we consider possible human effects due to ingestion of foods contaminated by stack releases of POHCs. No PICs, metals or fugitive releases are considered in these calculations. The ingestion risk estimates are adapted from two studies recently completed for EPA which consider possible ingestion risks around incinerators located in Southern California, Wisconsin and Missouri. Our procedures to adapt these results for this case study are described in Appendix D.

The results of our ingestion calculations show that ingestion risks are generally at least two orders of magnitude smaller than risks expected through inhalation. EDC wastes generate approximately 5 times more risk through the ingestion route than the PCB wastes.

Summary of Human Health Effects

The sections above summarize the human health risks from releases of hazardous materials at ocean- and land-based incinerators. These estimates are highly uncertain. The results of air dispersion models are generally assumed to be accurate to plus or minus 100 percent. Further, the CAG cancer unit risk factors are generally considered certain only to plus or minus one order of magnitude. As a result, the health risk estimates have more meaning as relative indicators of risks from land- versus ocean-based systems than as absolute estimators of the levels of those risks.

Exhibit 8-5 summarizes the human health risk estimates for releases from land- and ocean-based systems. The figures in this exhibit are for inhalation risks to the most exposed individual only. As the exhibit shows, the incremental risks generated by the inhalation of pollutants are lower for the ocean-based incinerator than they are for either our Arkansas or Texas incinerators. For both the ocean and land case the total risks are dominated by the risk from metals (as mentioned earlier, our analysis probably overstates risks from metals). Although more metals are emitted from the stack in the ocean case, they travel several hundred kilometers from the burn site to Brownsville before they are inhaled by the most exposed individual. Thus, despite the higher emission rates, the risks to the most exposed individual from an ocean-based incinerator are below those for the land-based case.

A recent study prepared by EPA estimated risks to human populations across the United States from inhalation of air toxics. (_The Scope and Magnitude of the Air Toxics Problem in the United States_, E. Haemisegger, A. Jones, B. Steigerwald, V. Thomson, September 1984). In this study the total risk from air toxics at various locations throughout the U.S. is estimated to range from 4 to 6 in 10,000 for the average individual. The most exposed individual risks estimated for land- and ocean-based incinerator releases are lower than risks to the average person from air toxics estimated in this broader study.

ENVIRONMENTAL EFFECTS

Ocean-Based Incineration

Environmental effects could occur from deposition of ocean incineration stack emissions onto the ocean's surface or from other releases which enter the ocean during normal operations. As explained in Chapters 5 and 6, we assume that stack emissions are the only release expected during normal incineration activities. (The effects of accidental releases due to a vessel casualty are discussed in Chapter 7.) This section of Chapter 8 considers the possible effects on the marine environment of POHCs, metals and HCl contained in the stack emissions. ASA evaluated the possible effects of these materials on the marine environment. Their analysis in this area is included as Section 5 of Appendix I, and is summarized below.

The entry of atmospheric pollutants into the ocean is mediated by the surface layer, and particularly by the "microlayer." The microlayer, generally defined as the top 100 micrometers at the air-sea interface, has been shown to have very high levels of biological activity and pollutant concentrations. Physical and biological processes in the microlayer are not well known, and time and resources have not permitted the inclusion of the microlayer in the marine ecosystems model developed by ASA and described in Chapter 7 and Appendix I. Thus, only qualitative and relatively uncertain conclusions can be drawn at this time concerning the effects of POHC and metals deposition on the ocean. The effects of chlorine deposition are better understood.

In analyzing possible marine effects from POHCs, ASA considered only PCBs. (Because EDC is highly soluble in water and volatilizes rapidly, the effects of deposition of EDC into the ocean is not of concern.) Analysis using ASA's atmospheric and marine transport models indicates that concentrations of PCBs in the water column during incineration would be about four orders of magnitude below the concentrations resulting from background deposition of PCBs.2/ Once the burn is completed, these concentrations decline to an even smaller fraction of background. Thus, concentrations of PCBs in the water column as a result of incinerator plume deposition should have no observable effect on the marine ecosystem.

A second potential ecosystem effect of PCB deposition is the accumulation of PCBs in the ocean flow sediments, resulting in increase in PCB concentrations in the benthos, demersal fish and pelagic fish. At a PCB emission rate of 5.25 E-3 kilograms per hour, ASA's analysis indicates that PCB deposition will have no significant impact on the marine ecosystem.3/

2/These results were derived by scaling the concentrations presented in Appendix I (based on an emission rate of one kilogram per hour of PCBs) to reflect the assumed PCB emission rate of 5.25E-3 kilograms per hour.

3/Once again, these conclusions are based on ASA's analyses in Appendix I, which employ a PCB emission rate of one kilogram per hour. At the one kilogram per hour emission rate, deposition has a significant impact on the ecosystem. However, at the assumed emission rate, the impact is negligible. (Personal communication, Dr. Mark Reed, November 1984).

This conclusion is supported by analysis showing that the atmospheric flux of PCBs to the Gulf waters is much greater than that expected from the Vulcanus. For example, the annual deposition of PCBs from stack emissions to the area affected by the plume (about 100,000 square kilometers) would be about 2 orders of magnitude less than the annual atmospheric flux to that area. Similarly, the deposition of PCBs from stack emissions would be about 3 orders of magnitude less than the atmospheric flux of PCBs to the entire Gulf. (In the mid-seventies, PCB concentrations in the atmosphere above the Gulf were higher by about an order of magnitude, suggesting that background flux, at one time, was 3 to 4 orders of magnitude greater than the deposition of PCBs expected for the Vulcanus.)

In assessing the possible effects of deposition of metals on the ocean, ASA assumes that arsenic, cadmium, chromium and nickel each are present in the waste feed at concentrations of 100 parts per million and are emitted from the stack as free metal ions. In general, these metals will be complexed as oxides or adsorbed to particulates as they fall out from the stack gas plume. Once on the ocean, remaining free metals will largely be adsorbed onto organics in the microlayer. Thus, it is likely that much of the metal fallout will be rendered non-toxic.

For modeling purposes, ASA employs a "generic" metal having the average specific gravity, particle diameter, and molecular weight of the four metals of interest. Based on these characteristics, ASA's atmospheric transport model predicts that 60 percent of the metals released from the Vulcanus' stack during a single burn will be deposited in a 7,500 square kilometer area of the Gulf before the plume reaches shore. ASA then calculates the concentration of each metal if mixed to depths of 100 micrometers (i.e., all metals are retained in the microlayer), 1 meter, and 60 meters. Cadmium would exceed background concentrations at all three mixing depths, albeit by less than a factor of two in the 60-meter case. None of the other metals, however, would exceed background levels at either the 60 meters or 1 meter mixing depths. If mixed only in the microlayer, all metals would greatly exceed background levels, as would be expected. The impact of these high concentrations on the microlayer is unknown at this time, though ASA notes that measured concentrations of metals in the microlayer range from one to fifty times surface-water background levels. Again, most metals would not be in a reactive state when entering the ocean, and most reactive metals that enter would be complexed and rendered non-toxic in passing through the microlayer.

Because their calculations assume that all metals are retained within the mixing layer for the duration of an 11-day burn, ASA believes that the 100 micrometer and 1 meter mixing depths are unrealistic, and that the results of the 60-meter case provide a reasonable worst-case prediction of metals concentrations. The toxic effects of the slight increases in metals concentrations shown in this case are dependent on the degree of complexation and adsorption the metals undergo, but in any case are likely to be small.

As shown previously, large amounts of chlorine in the form of hydrochloric acid (HCl) will be emitted during incineration of highly chlorinated wastes such as PCBs and EDC. Seawater has a large buffering capacity and can absorb up to about 1 M mole of HCl per liter before the pH changes significantly. Given this figure and assuming daily renewal of the Gulf's surface layer, ASA estimates that all of the HCl from a 6-day burn of EDC wastes deposited within 14 kilometers of the ship could be mixed in the top one centimeter of ocean with no effect on the water's pH level. Given the normal renewal of the sea surface layer, the turbulence of the upper 2-3 meters of the Gulf and the high probability that the HCl will be deposited over a much larger area, mixing would be sufficient to absorb all HCl released with no noticeable effect on the marine ecosystem.

Land-Based Incineration

Hazardous materials released from land-based incinerators could damage both terrestrial and marine ecosystems. However, land-based units are generally equipped with scrubbers that capture metals and chlorine before these materials are released from the stack. While we did not consider the possible effects of POHCs, PICs or metals from land-based units on the environment, we asked Arthur D. Little, Inc. (ADL) to judge qualitatively the possible environmental effects of scrubber effluent and sludge. ADL's analyses in this area are included in Appendix F. The paragraphs below summarize ADL's findings.

Scrubber effluent or "blowdown" contains small amounts of chloride and is disposed in several ways at existing commercial incinerators. At one location the effluent is sold as a feedstock to a nearby chemical plant; while at other locations the effluent is discharged via deep wells, evaporation ponds, or waste water treatment plants. Direct or indirect discharges to receiving water bodies must meet permit requirements and thus adverse environmental effects are unlikely from these releases. Similarly, disposal to deep wells is regulated and is unlikely to cause adverse environmental effects.

Scrubber sludges are generated through the neutralization and precipitation of scrubber effluent. The resulting solids include particulate matter, metal precipitates and crystaline calcium or sodium compounds (depending on the alkali base used in the system). In general, these sludges must be disposed in a surface impoundment or landfill meeting RCRA permit requirements. If these permit requirements are met, no adverse environmental effects are expected.

Summary of Environmental Effects

The sections above consider some of the environmental effects possible from releases of hazardous materials from land-based and ocean-based incinerators. The analysis of these effects is qualitative. For ocean-based systems, environmental effects will be determined largely by the effect of incinerator releases on the microlayer. The magnitude of these effects is uncertain but is likely to be small. For land-based systems, the impact of scrubber operations on the environment is also judged to be small. Other possible effects on the environment are not considered.

SUMMARY

This chapter presents estimates of the effects of releases from ocean- and land-based incinerator operations. Human health effects are expected to be relatively small for land- and ocean-based systems. Environmental effects from ocean-based operations are uncertain at present due to lack of scientific data on the importance and role of the microlayer but are likely to be small. Risks from POHCs emitted from the ocean-based system will typically be smaller than POHC risks at land-based facilities. Greater uncertainty is associated with the relative risks from PICs. However, it is unlikely that the risk from PICs emitted from an ocean-based system would exceed the risk from PICs at land-based facilities. Risks from metals are somewhat lower for the ocean-based incinerator although these results are sensitive to changes in the efficiency of scrubbers at the land-based facilities. Environmental effects from land systems are not considered completely, but the effects of scrubber operations are expected to be small.

Exhibit 8-1

INCREMENTAL RISK TO MOST EXPOSED INDIVIDUAL FROM OCEAN-BASED STACK EMISSIONS

Constituent	PCB Waste	EDC Waste
Stack POHCs	1.45E-10	5.51E-10
Stack PICs	1.68E-12	3.36E-9
Metals	6.37E-7	1.06E-6
TOTAL	6.37E-7	1.06E-6

Source: Appendix G, Exhibit G-30

Exhibit 8-2

EXPOSURES DUE TO FUGITIVE EMISSIONS AT CHICKASAW AND AT THE TEXAS AND ARKANSAS FACILITIES

	Aggregate Exposure (person-ug/m3)	Maximum Concentration (ug/m3)	MEI Concentration (ug/m3)
Chickasaw			
PCB Waste	3.70E+3	8.47E-4	2.20E-5
EDC Waste	5.90E+3	1.35E-3	3.50E-5
Texas Incinerator			
PCB Waste	6.68E0	7.96E-3	1.51E-4
EDC Waste	9.48E0	5.87E-3	9.32E-5
Arkansas Incinerator			
PCB Waste	4.59E0	1.69E-3	1.38E-3
EDC WAste	6.60E0	1.19E-3	9.72E-4

Source: IEc Analysis

Exhibit 8-3

INCREMENTAL RISK TO MOST EXPOSED INDIVIDUAL FROM ALL OCEAN-BASED EMISSIONS

Constituent	PCB Waste	EDC Waste
Stack POHCs	1.45E-10	5.51E-10
Stack PICs	1.68E-12	3.36E-9
Metals	6.37E-7	1.06E-6
TOTAL	6.37E-7	1.06E-6
Transfer/Storage		
Chickasaw	2.02E-8	4.97E-10

Source: Appendix G, Exhibit G-30 and IEc Analysis

Exhibit 8-4

INCREMENTAL RISK TO MOST EXPOSED INDIVIDUAL FROM LAND-BASED EMISSIONS

	Texas		Arkansas	
Constituent	PCB Waste	EDC Waste	PCB Waste	EDC Waste
Stack POHCs	6.10E-8	1.70E-7	4.16E-8	1.16E-7
Stack PICs	2.13E-6	3.07E-8	1.45E-6	2.10E-8
Metals	2.14E-5	2.61E-5	2.98E-5	3.63E-5
Fugitives	1.39E-7	2.96E-9	1.27E-6	3.09E-8
Total	2.37E-5	2.63E-5	3.25E-5	3.65E-5

Source: Appendix D, Exhibit D-8

Exhibit 8-5

SUMMARY OF INCREMENTAL HUMAN HEALTH RISKS TO MOST EXPOSED INDIVIDUAL

Location	PCB Waste	EDC Waste
Land-based System		
Texas	2.37E-5	2.63E-5
Arkansas	3.25E-5	3.65E-5
Ocean-based System		
Coastline	6.37E-7	1.06E-6
Chickasaw	2.02E-8	4.97E-10

Source: Exhibits 8-3, 8-4